FIRE EFFECTS ON PACIFIC NORTHWEST FOREST SOILS

DONALD E. BOYER
AND
JOHN D. DELL

Forest Service - USDA
Pacific Northwest Region
Watershed Management
and
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BY:

DONALD E. BOYER

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AUTHORS

Donald E. Boyer is a Soil Management Specialist with Watershed Management staff in the Regional Office, Pacific Northwest Region, USDA Forest Service. He has been in this position since 1967. From 1954 to 1957 he worked at the Soils Testing Laboratory in Ft. Collins, Colorado and from 1957 to 1963 conducted soil surveys in western Colorado while with the Soil Conservation Service. In 1963, he transferred to the Forest Service in the Intermountain Region as a Zone Soil Scientist for National Forests in Utah and Nevada.

John D. Dell is a Forester assigned to Aviation and Fire Management staff, Pacific Northwest Region, USDA Forest Service. He has had functional assignments in timber and fire management on several National Forests in California. His background includes nearly ten years as a fire researcher with the Riverside Forest Fire Laboratory and Pacific Northwest Experiment Station. He has been in his current position as the Regional Fuels Management Specialist since 1972.

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PREFACE

All numerical values given in this publication are expressed in the metric system and followed, in parenthesis, with the English equivalent. A conversion Table is also provided in the Appendix to aid the reader.

SUMMARY

Most of the research literature provides useful information relative to surface temperatures as they effect soils. Surface temperatures attained in burning, however, are an elusive factor to use in the prediction process. The amount of forest floor material consumed, or "duff reduction", appears to offer a more reliable "measuring-stick" for predicting the outcome of prescribed fire. Although temperatures are an important concern, when the fuels manager properly designs his prescription to minimize the quantity of duff reduction, then the surface temperatures will not exceed the critical levels. This publication is designed to provide the basic concepts of the surface temperature relationships, but most importantly to illustrate the usefulness of the "duff reduction" approach.

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SECTION I.

INTRODUCTION

I. INTRODUCTION

One of the key objectives of this publication is to provide a practical and comprehensible state-of-knowledge guide on fire and soil relationships geared specifically to conditions found in the Pacific Northwest. We have attempted to develop this material so it can be understood and used by foresters involved in various functional areas (fire, timber, watershed management, etc.).

Fire is a powerful molder of Pacific Northwest forest ecosystems. Depending on its frequency, intensity[1/] and duration it can induce considerable change in microclimate and vegetation. Fire can cause significant effects on interception, evaporation, transpiration, storage, and movement of water in forest stands and soils. Mutch (1976) points out that the underlying strength of fire management rests in the subtle weaving of a fundamental understanding of fire as an ecosystem process into the day-to-day fabric of resource management. The effects of different intensities of fire on soils and various other specific resource concern areas needs thorough analysis and better understanding in order to provide a basis for effective application of fire as a natural process and as a management tool.

Most of our current knowledge of the effects of fire on Northwest soils is derived from observations taken on past wildfires and high intensity slash burns - particularly broadcast burning of clearcut areas. Many of these studies were done several years ago, prior to more recent trends in improving harvesting methods and the intensive wood utilization we see today. As an example, the current practice of yarding unmerchantable material (YUM) from the logging slash complex can have a considerable modifying effect on resultant slash burn intensity and duration. These relationships, however, are not defined in most of the available research literature on fire effects on soils. This void of our state-of-knowledge is pointed out by Wells et al. (1979) in their comprehensive report on Effects of Fire on Soil, developed as a product of the National Fire Effects Workshop held in Denver, Colorado in 1978. In this report the authors emphasize the need for evaluating those burning situations where fire effects are less dramatic than during wildfires, so the tradeoffs between prescribed burning and/or other means of vegetation manipulation can be compared.

A specific objective of this paper is to provide, on a Regional basis, detailed discussion and illustration of fire effects on soils for use by forest managers. This information, properly interpreted, can be used to provide technical input to land management planning and for improving success and quality of our prescribed burning programs - particularly in relation to soil protection and enhancement. The information derived can also provide a useful reference source for analyzing wildfire damage and determining fire rehabilitation needs.

Martin and Dell (1978) point out that today forest managers have come to realize that fire, if managed properly, can actually help maintain many of our resources in a condition that is more ecologically stable, as well as more pleasing and useful to man. By using fire judiciously, the forester can work with the natural system more economically and rationally - rather than trying to force the system into unusual patterns.

1/ Defined as the rate of heat released per unit of ground surface area, proportionate to flame length and at times the rate of fire spread (see page 8).

Wright and Heinselman (1973) presented a comprehensive summary of fire as an ecosystem process in fire dependent northern conifer forests. They point out some of the key influences that fire can exert on the forest:

- Fire influences the physical-chemical environment.
- Fire regulates dry-matter accumulation.
- Fire controls plant species and communities.
- Fire determines wildlife habitat patterns and populations.
- Fire controls forest insects, parasites, fungi, etc.
- Fire controls major ecosystem processes and characteristics (nutrient cycles, energy flow, succession, diversity, productivity, and stability).

Forest soils are affected, in some way, by all of these factors. It is important to emphasize that the effects of fire on soils are extremely variable, making any generalization difficult and often misleading. Frequency, duration, and intensity of fire, organic material present and amount consumed, and character of the soil must all be considered. Each situation must be individually and specifically appraised.

It is the intention of the authors to provide in this paper, a compendium of useful information geared specifically to the effects of both high and low intensity fire on soils in the Pacific Northwest. The work represents the best state-of-knowledge that can be assembled at this time. We realize there is a great deal more to be learned as we advance in the technology of fire management and soil science. As such knowledge is developed we will attempt to update and improve the information herein. In the meantime, this paper will help the forester understand the relationship of fire and soils, provide guidelines for analyzing fire effects, identify and suggest standards, predict results of fire use, prescribe acceptable applications of fire, and suggest monitoring procedures to evaluate results.

SECTION II.

UNDERSTANDING THE RELATIONSHIP OF FIRE AND SOILS

II. UNDERSTANDING THE RELATIONSHIP OF FIRE AND SOILS

To better understand the effects of fire on the soil resource, a familiarity with the behavior of fire is essential. Clive Countryman, formerly with the Pacific Southwest Forest and Range Experiment Station, has authored a series of booklets on "Heat and Wildland Fire" (Countryman 1975, 1977a, 1977b) that are designed to acquaint the reader with important concepts of fire behavior and the application of these concepts to wildland fire problems. His treatment of this subject is well structured and provided the foundation, through excerpts, for the following section.

The Nature of Heat

Heat is part of an energy system. The sun supplies radiant energy to plant materials which is transformed through photosynthesis to chemical energy. Fire transforms the chemical energy in the plant materials to thermal and radiant energy and subsequently to kinetic energy in the rising air or heat column. Heat is measured in joules, calories or British thermal units (Btu). The calorie is arbitrarily defined as 4.1840 joules and is very nearly equivalent to the amount of heat needed to raise the temperature of one gram of water from 14.5°C to 15.5°C (58.1 to 59.9°F). A Btu is equal to 1055 joules or 252 calories. The heat produced in one second by a current of one amphere through a resistance of one ohm is a joule and is the standard unit of heat. However, all three units are commonly used although the calorie and Btu are no longer connected in any way with the properties of water. Complete combustion of a kilogram (2.2 lbs) of wood will release about 20,000 kilojoules or 4778 calories or 18.920 Btu or 8600 Btu/lb.

Specific heat is the quantity of heat needed to raise the temperature of a unit weight of a substance 1°F, while heat capacity is the quantity of heat required to raise the temperature of a unit volume by 1°F. Specific heat is usually expressed as Btu per pound per degree Fahrenheit (Btu/lb/°F) or as calories per gram per degree Celsius (cal/g/°C). Materials with high specific heats require a large amount of heat to increase their temperature and contain more heat at a given temperature than do materials of low specific heats. The specific heat of many materials varies considerably with temperature, so the temperature at which the specific heat was determined is usually specified. Water, with a specific heat of 1.0 Btu/lb/°F at ordinary atmospheric temperature has one of the highest specific heats of common substances. The specific heat of most metals is low. Lead, for example, has a specific heat of only 0.031 Btu/lb/°F at 32°F and requires very little heat to increase its temperature. Most wildland fuels have specific heats in the range of 0.45 to 0.65 Btu/lb/°F.

Often information on the amount of heat needed to produce a given temperature change in some volume of a material is needed. The amount of heat needed to raise the temperature of a layer or volume of fuels is important because it helps determine the characteristics of a firebrand that can ignite or carry a fire in a particular fuel. Heat capacity is calculated from the density and the specific heat of a substance and is often expressed in Btu/ft^3/°F. Materials with high heat capacities can adsorb and lose large quantities of heat without much temperature change. Conversely, relatively little heat is needed to change the temperature of materials with low heat capacity. At ordinary temperatures, the heat capacity of air is about 0.017 Btu/ft^3/°F; little heat is needed to change its temperature. Under similar conditions, the heat capacity of dry soil and rock is 19 to 20 Btu/ft^3/°F, and that of water is about 62 Btu/ft^3/°F.

Because the specific heat of most wildland fuels varies over a relatively narrow span, differences in heat capacity of the fuels depend chiefly on their density. The differences in density of wildland fuels are quite large and variations in heat capacity are also. Douglas-fir has a dry density of about 28 lb/ft^3 while that of punky and decayed wood may be only 6 or 7 lbs/ft^3. The Douglas-fir, then, requires a considerable amount of heat to raise its temperature to the ignition point, but decayed wood requires a relatively small amount. Therefore, heat capacity is an important characteristic in the ignition of wildland fuels.

A considerable amount of heat is often involved in the change of state of a substance. The amount of heat needed to change a liquid to a vapor, or released when the vapor is converted to a liquid, is the heat of vaporization. Heat released or absorbed in the changes of state of water or heat needed to vaporize the moisture in fuels has an important effect on the ignition of a fuel and the rate at which it burns.

Heat transfer is of paramount importance in wildland fire behavior. Heat can be transferred in three ways: by conduction, by radiation, or by convection. Usually all three methods of heat transfer are operating at the same time in a wildland fire.

Heat conduction is the transfer of thermal energy by molecular activity from one part of a substance to another part, or between substances in contact. The energy is transferred without appreciable movement or displacement of the substance as a whole. Different substances vary widely in molecular structure and the number of molecules they contain. Consequently, the ability of various substances to conduct heat also varies over a wide range. Metals are usually good conductors, but substances like air, wood, glass, water or soil conduct heat slowly. Wildland fuels in general are poor heat conductors.

The rate at which heat can be conducted depends on the ability of the substance to conduct heat and on the temperature gradient within and between substances - the larger the temperature gradient, the more rapid the conduction rate. The quantity of heat conducted depends also on the area through which the heat is transferred. These factors are brought together in the term thermal conductivity, which expresses the quantity of heat transferred per unit of area per unit of time per degree of temperature gradient. Thermal conductivity is often given as Btu per hour per square foot per degree F per foot of distance $Btu/hr/ft^2/°F/ft$. Dead ponderosa pine needles have a density about 5 times that of Douglas-fir, and a thermal conductivity nearly 3 times as great: 0.07262 $Btu/hr/ft^2/°F/ft$. In contrast, maple wood has a thermal conductivity of 0.09199 $Btu/hr/ft^2/°F/ft$.

When heat is applied to a substance, the amount and rate of temperature rise at any given point in the substance is controlled by the thermal conductivity, specific heat and density of the substance. Taken together, these factors establish the thermal diffusivity of the substance. The greater the thermal diffusivity, the less the amount of heat needed to raise the temperature. The relationship of thermal diffusivity to thermal conductivity, specific heat, and density is given by the equation:

$$\text{Thermal diffusivity} = \frac{\text{Thermal conductivity}}{\text{Density x specific heat}}$$

Specific heat of wildland fuels tends to increase with increasing density. Consequently, thermal diffusivity decreases as the fuel density becomes greater. Because fuels with low density have higher thermal diffusivity, low density fuels, such as decayed wood, can usually be ignited with less heat, or in a shorter time with the same amount of heat, than can fuels of greater density.

The Nature of Fire

Organic materials, such as wildland fuels, do not burn directly, but must first be converted to gases by pyrolysis, a chemical process brought about by heat. Radiation and convection can transfer the necessary heat to the surface of the fuel, but transfer of heat into the interior is almost entirely by conduction.

Ignition of wildland fuels require a finite quantity of heat, and this heat must be supplied at a rate adequate to generate sufficient gases to produce a flammable mixture, and at a temperature high enough to cause the gases to flame or the char to glow.

When heated, fuels first produce water vapor and other gases that are mostly noncombustible. Not until the fuel temperature reaches 204°C (400°F) or more do significant amounts of combustible gas begin to appear, and the fuels begin to discolor or char. At about this temperature too, the pyrolysis begins to become exothermic - the chemical reaction produces more heat than it needs to sustain itself. If the heat losses are small, pyrolysis may become self-sustaining, and the temperatures continue to rise without an outside heat source. As the temperature of the fuel continues to rise, combustible gases are produced more rapidly and the chemical reactions become more strongly exothermic, reaching a peak about 315°C (600°F). Although combustible gases are generated at temperatures above 204°C (400°F), they will not flame even when mixed with air until their temperature reaches 427°C to 482°C (800°F to 900°F).

The pilot ignition temperature has been studied by various researchers and it appears to range between 300°C to 380°C (572°F to 716°F). A temperature of 320°C (608°F) has been accepted as pilot ignition point for most ground forest fuels.

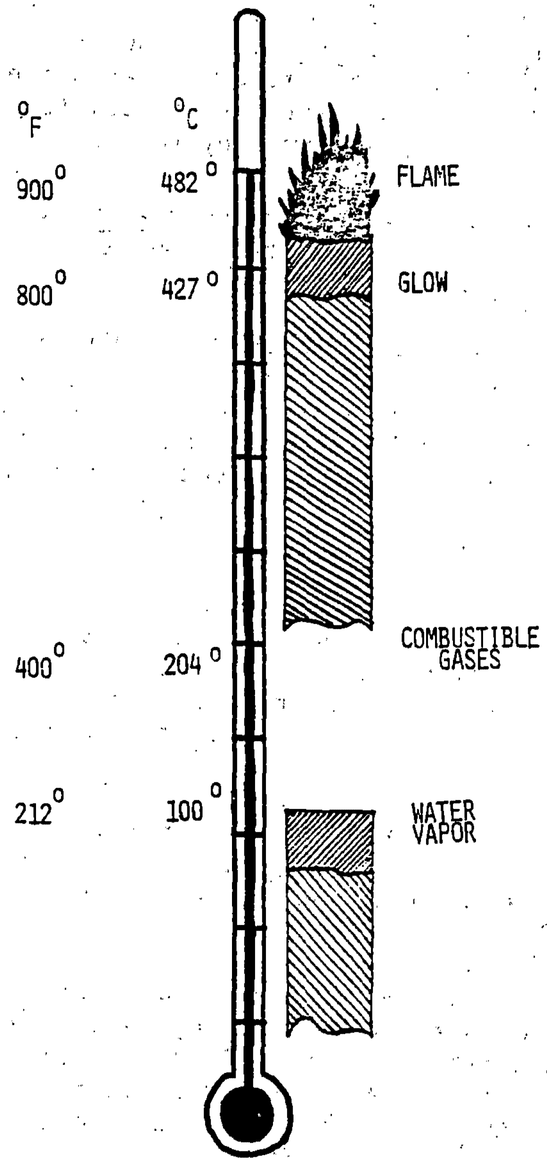

Figure 1 - Fuel Combustion Thermometer (from Countryman, 1977b)

The maximum temperature that can be produced by the burning of gases generated from wildland fuels is believed to be between 1927°C to 2200°C (3500°F and 4000°F) with an ideal mixture of gas and air. Temperatures exceeding 1650°C (3000°F) have been measured in exceptionally intense fires in the flame itself. The ideal mixture of gas and air is not likely to occur often during most wildland fires, however, since there is usually considerable cooling of the flames by mixing with cooler air. As a result, flame temperatures in the range of 980°C to 1370°C (1800°F to 2500°F) are more common.

Moisture in fuel increases the ignition time and slows the pyrolysis process by increasing the amount of heat required to raise the fuel to a temperature where combustible gases are produced, by absorbing through evaporation, part of the heat otherwise available for pyrolysis and by diluting the gases produced by pyrolysis.

Albini (1976) provides an application of this concept in his discussion on "moisture of extinction." This term relates to the percentage of fuel moisture at which fire could no longer spread. "For cases in which only dead fuel components are present, the moisture of extinction has been experimentally evaluated (although not for a wide range of situations) and seldom exceeds 30 percent of dry fuel weight. Thirty percent represents a fiber-saturation condition, but fuel moisture can exceed this value."

He further states that for light-airy fuels such as fine grass, the moisture of extinction is about 12 to 15 percent. Fifteen percent appears to be the value for open beds of assembled slash fuel, while 25 to 30 percent was observed for beds of pine needles.

Small size fuels ignite more easily and produce heat at a faster rate than large fuels because of their greater surface area to volume ratio and thinner layers of char permits more rapid heat conduction. Therefore, small fuels in the fuel bed contribute most to the main flame wave that largely controls the fire behavior. Large fuels usually require an external heat source for complete combustion and frequently stop burning when the fine fuels have burned out.

Although this is an oversimplified discussion on the physics of heat and fire, it is intended to provide a basis for understanding the units of measure and, hopefully, to stimulate the reader into exploring some of the exceptional work done by fire behavior researchers such as Frank Albini. In his publication titled "Estimating Wildfire Behavior and Effects" (Albini 1976), he provides an objective view of some of the fire behavior prediction models available to fire managers and other concerned resource specialists. As he states "To plan prescribed fires to achieve stated objectives, to minimize cost of control and mop-up, and to reduce the risk of escape or undesirable behavior, a firm basis of fire behavior estimation must be established. This basis should include not only the gross behavior of the fire but its effects on the surrounding environment. So, predictive models that allow the estimation of spread rate, intensity, flame length, crown scorch height, etc. should be useful in prescription formulation ...." Therefore, to understand the concepts behind the models and to apply these models an acquaintance with the terms and units of measure are essential.

The rate of advance of the "head" of a fire is the forward rate of spread and is usually expressed in terms of velocity; i.e, "chains per hour." The behavior potential of fire considers the rate of spread as the spread component and the energy release component. The spread component model integrates the effect of wind, slope, and fuel bed and fuel particle properties. The energy release component model estimates the potential available energy released per unit area in the flaming zone of the fire. The energy release component is derived from predictions of the rate of heat release per unit area during flaming combustion and the duration of flaming. These models are discussed in detail in the National Fire-Danger Rating System - 1978 (Deeming et al. 1978).

Intensity of fire includes two separate measuring techniques; that is, reaction intensity and fireline intensity. Reaction intensity is the rate of heat release per unit of ground beneath the fuel bed. "As the front of the flaming zone moves over some point on the ground, the reaction intensity increases from zero to some maximum value and then decreases to zero (much more slowly than it increases usually), as the available fuel is consumed." (Albini 1976). This measurement is expressed in Btu/ft^2/min. or Kcal/m^2/sec. Fireline intensity, commonly referred to as Byram's fireline intensity, is the product of available heat of combustion per unit area of the ground and the rate of spread of the fire. The expressions of this product are heat energy/length/time or Btu/ft/sec. or Kcal/m/s. (Albini 1976). The average length of the flame at the edge of a free-burning fire can be predicted by the fireline intensity (Albini 1976).

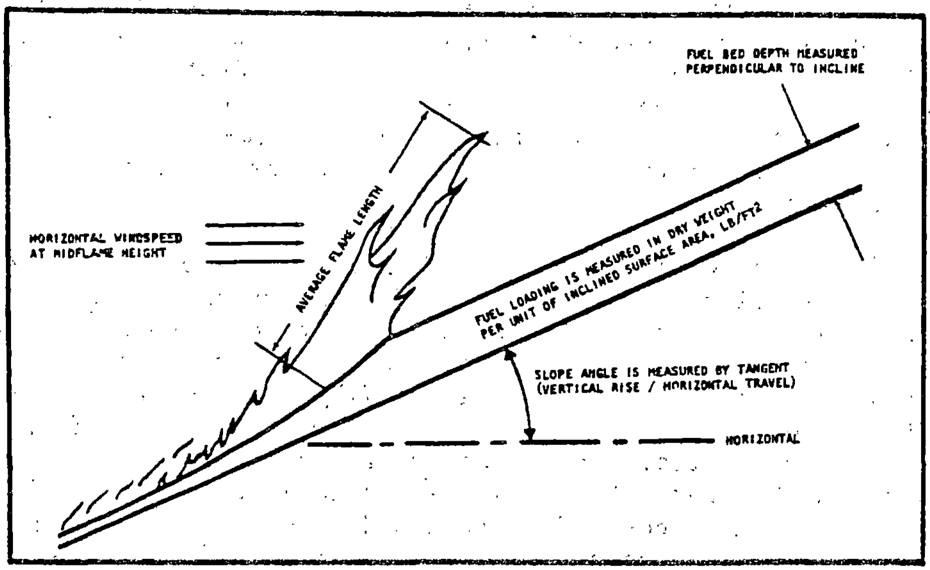

Figure 2 - Explanation of nomenclature used in describing fire spread model and input variable definitions (from Albini 1976).

Crown scorch height is the maximum height of lethal scorching of conifer needles. It has been found that it is a function of intensity, ambient temperature and windspeed. "The mechanism by which needle scorching occurs is probably simply killing the live tissue, as it seems strongly correlated to an air temperature level of about 60° C (140° F), which approximate temperature level has been noted to be lethal to conifer foliage on exposures of 30 seconds to 1 minute (Hare 1961)", (Albini 1976).

The Thermal Properties of Soil

A consideration of the physical properties of fire has application in the assessment of the physical properties of soil. Heat flux density and thermal properties of the soil control the degree and extent of temperature change as a result of fire. Simply stated, various soils respond differently to comparable intensities of fire. As mentioned previously in the section on the nature of heat, the term thermal conductivity is the quantity of heat that flows through a unit area in a unit time under unit temperature gradient. Thermal diffusivity is the ratio of the conductivity to the product of the specific heat and density.

Two new terms need to be introduced: Volumetric heat capacity and thermal contact coefficient. Volumetric heat capacity is the product of the specific heat and the soil density. The quantity of heat which must be supplied to a 1-centimeter cube to raise its temperature 1°C is known as the volumetric heat capacity of the cube and is expressed in calories per cubic centimeter per degree Celsius. Thermal contact coefficient is a term used to indicate how much the surface temperature will vary when heat is supplied to or removed from the surface.

Soils with low thermal conductivities and low volumetric heat capacities have high surface temperatures during the day and low surface temperatures during the night. Frost and heat injury to young plants are more likely on such soils.

The value in assessing the thermal properties of the soil are basic to developing interpretations and have been illustrated by Cochran (1969):

Table 1. Thermal Properties of Soils

	Consequence of: Low Values	High Values
Thermal Conductivity	Slow heat transfer with constant temp. gradient.	Rapid heat transfer with constant temp. gradient.
Volumetric Heat Capacity	Large temperature responses to given amount of added heat.	Small temperature responses to given amount of added heat.
Thermal Diffusivity	Heat will not be transferred to as great a depth in a given time.	Heat will be transferred to a greater depth in a given time.
Thermal Contact Coefficient	Greater variation in surface temp.	Lesser variation in surface temp.

Of all the various soils in Region Six, the pumice soils have the most distinct and unique properties. Cochran (1969) has stated: "Pumice soils have much lower thermal contact coefficients and thermal diffusivities than denser mineral soils." Or, stated simply, they can have greater variations in surface temperatures but heat will not be transferred to as great a depth in a given time. Cochran (1969) has also provided some thermal properties of the Lapine A1 horizon (the surface mineral soil layer of an extensive pumice soil of the Deschutes and Winema National Forests) and comparable values from van Wijke (cite of Cochran 1969) for a peat, a clay, and a sand:

Table 2. Thermal properties of selected soils and peat

Material	Water content cm^3/cm^3	Thermal conductivity $(cal/sec{:}cm^{-1}{}^\circ C^{-1})$	Heat capacity $(cal/cm^3{}^\circ C^{-1})$	Thermal Diffusivity $(cm^2 sec^{-1})$	Thermal contact Coefficient $(cal/cm^{-2}\ sec/{}^\circ C$
Pumice A1	.0	.00033	0.16	.0024	.0071
"	.10	.00057	0.25	.0023	.0120
"	.20	.00087	0.35	.0025	.0165
"	.30	.00102	0.45	.0023	.0216
"	.40	.00160	0.55	.0021	.0253
Peat	0	.00014	0.12		0.0041
"	.40	.0007	0.52	.0014	0.0191
Clay	0	.00060	0.30		0.0134
"	.40	.0038	0.70	.0054	0.0515
Sand	0	.0007	0.30		0.0145
"	.40	.0054	0.70	.0077	0.0615

The effect of fire on soil is a function of duration and intensity. The transfer of heat to the soil is dependent upon the physical characteristics of the soil itself. For example, a quantity of heat applied for a given period of time will have an effect to a greater depth on a sand as opposed to a "pumice" soil. This is important in the prediction of water repellency and the depth of penetration that might be expected.

Another interpretation that can be made from the table presented above is that on "pumice" soils, specifically, where heat injury and frost heaving is a problem, the removal of the duff would be beneficial. This is particularly true when there is shade from a layer of fuel material to moderate the temperature extremes for the seedlings. Another possibility is to leave as much material, following timber harvest, as the objectives of fuels management will allow.

Different Levels of Burn Intensity

As one can visualize, temperature variations can occur both laterally and vertically within, for example, a prescribed burn of a logging slash area. When considering the soil resource, we are concerned with the temperatures at the soil or duff surface. Utilizing some tentative data provided by Kevin Ryan, (formerly of the Pacific Northwest Forest and Range Experiment Station in Seattle, currently with the Forest Fire Laboratory in Missoula, Montana) and descriptive terms mentioned in work by Morris 1970, Dyrness and Youngberg 1957, and Ralston and Hatchell 1971, we can describe the various levels of fire intensity:

Lightly burned: The surface duff layer is often charred by fire but not removed. Duff, crumbled wood or other woody debris partly burned, logs not deeply charred.

In clearcuts: Surface temps of <200°C (390°F).
In underburns: Surface temps of <180°C (350°F).
Surface temps of 177°C produced soil temps of 71°C @ 2.5cm.

Moderate burn: Duff, rotten wood or other woody debris partially consumed or logs may be deeply charred but mineral soil under the ash not appreciably changed in color.

In clearcuts: Surface temps of 200°C-500°C (390°F-930°F).
In underburns: Surface temps of 180°C-300°C (350°F-590°F).
Surface temps. of 400°C produced soil temps. of 177°C @ 2.5cm.

Severe burn: Top layer of mineral soil significantly changed in color, usually to reddish color; next one-half inch blackened from organic matter charring by heat conducted through top layer.

In clearcuts: Surface temps of >500°C (930°F).
In underburns: Surface temps of >300°C (590°F).
Under piles: Surface temps of >650°C (1200°F).
Wildfire: Surface temps. of >760°C (1400°F).
Surface temps of 500°C produced soil temps. of 288°C @ 2.5cm.

Another manner of expressing burn intensities is an adaptation of the system used in the Fire Management Analysis for Forest Planning, Draft of January, 1980, USFS-WO (see Table 3).

Table 3. Fire Intensity

Approximate Fire Intensity Level	Fireline Intensity (Btu's/s/ft.)	Flame Length (Ft.)	Remarks
Low	0-25	0-2	Most light prescribed underburn burns in this range.
	26-115	2-4	About maximum for desirable prescribed underburning.
Moderate	116-520	4-8	Prospects for any direct frontal control are poor at this intensity and above. Not desirable for most underburning situations. Likely to occur in clearcut slash burning.
High	521-1260	8-12	Heat load on people within 30 ft.-dangerous. Very damaging to vegetation. May occur in heavy fuel concentrations in clearcut slash burning.
	1260-2350	12-16	Spotting fires, whirls and crowning to be expected.
	2351+	16+	

From this data, some appreciation for the energy release of burning fuels can be made.

There is no direct correlation between fireline intensity and temperature at the soil surface, but some estimations can be made by combining the two systems mentioned above. It can also serve as an aid in visualizing the character of the burning materials and the visual conditions that can be expressed following the burn.

Heat Transfer Within the Soil

In a study by DeBano, Savage and Hamilton (1976), using lab facilities, dry and wet sand and partially decomposed Coulter pine litter, the following information was developed (coil temp. of 760°C (1400°F), litter thickness of 2 cm.).

Table 4. Heat Transfer

Approx. Temp's in °C

Time Min.	Surface Dry	Surface Wet	1 cm. Dry	1 cm. Wet	2 cm. Dry	2 cm. Wet	3 cm. Dry	3 cm. Wet
5	100	85	60	50	25	35	25	25
10	200	135	100	90	70	70	45	50
15	290	200	170	90	90	80	70	70
20	315	260	210	120	120	95	70	85
25	370	290	245	160	150	100	95	95
30	340	285	260	160	180	100	120	95

The important factors that can be recognized from this table are the effects of temperature and duration on dry and moist materials and the insulating qualities of those materials. The wet sand is slow to respond to the heat source even though that temperature represents severe conditions. It can also be seen that the heat pulse of 760°C for 15 minutes on dry sand is about equal to 25 minutes on a wet sand. If duration, even at high temperatures, can be kept to a minimum, the heat pulse can be confined to very shallow depths.

SECTION III.

ANALYZING FIRE EFFECTS

III. ANALYZING FIRE EFFECTS

A. Types of Fire Activities. Fire activities can be catagorized into two headings: managed and unmanaged. Generally, wildfires are considered unmanaged fires and produce significantly different results which should not be confused with managed fires related to prescription burning for resource protection and enhancement. The following discussion (adapted from a presentation by DeByle (1976), and other sources as noted) aids in recognizing the end-results and cause-effect relationships associated with the two major types of fire activity.

Cycle Length:

Unmanaged fire: Variable within broad limits, naturally and human-caused. For example, some plant communities exhibit natural fire occurence cycles determined by aging and correlating dates from fire scars (Arno and Sneck, 1977). Some frequency correlations for Pacific Northwest timber types have been determined as follows:

Ponderosa pine/white fir	Crater Lake	10 to 15 yrs.
Ponderosa pine/bitterbrush	Crater Lake	5 to 15 yrs.
Ponderosa pine	E. Wash.	7 to 15 yrs.
Lodgepole pine	Crater Lake	50 to 80 yrs.
Pacific Silver fir	Mt. Rainier	approx. 450 yrs.
Western Hemlock/Douglas-fir	Olympic Pen.	450 + yrs.
Douglas-fir	Cascades	200-300 yrs.
Douglas-fir	Vancouver Islands	approx. 450 yrs.

(Source: J. K. Agee, 1979, personal communication)

Note: The significance of this information relates to the amount and size of fuel loadings that can be expected from certain plant communities. Such correlations can be useful in predicting the impacts of unmanaged fires in a given forest type.

Managed fire: Variable, may be as long as rotation age.

Area effected:

Unmanaged fire: Fire size ranges from small patches to thousands of hectares or acres.

Managed fire: Usually small or well-defined fire perimeter. Set within relatively narrow prescription limits.

Season:

Unmanaged fire: Usually occurs when driest conditions exist, such as late summer. However, it can occur in any season if critical conditions develop.

Managed fire: All seasons, with burning prescribed only when controllable.

Intensity:

Unmanaged fire: Intense burning frequently over long cycles, some low intensity burning at short intervals.

Managed fire: Broadcast slash burning ranges from low to severe depending on fuel amount, arrangement and topography. Piled slash usually results in severe intensity burning. Backing fires or strip head fires in underburning usually are low intensity.

Prior Soil Condition:

Unmanaged fire: Usually occurs on dry surface organic layers overlaid on dry mineral soil. Burning often results in pronounced heating of mineral soil.

Managed fire: Variable duff and soil moisture content, depending on season of burning. Usually no significant soil heating occurs except under burn piles or under heavy concentrations where heating is usually severe.

Resulting Soil Surface:

Unmanaged fire: Blackened and frequently burned to mineral soil layers. Soil colors reddish under extreme heating conditions.

Managed fire: Blackened after broadcast burning, mineral soil exposed on 5 to 25% of area. [Machine piling of slash bares mineral soil upwards to 75% of area between piles with reddening of soil under completely burned piles. In machine piling, surface organic layers are often scraped away, mixed into mineral soil or compacted into mineral soil. Although this is not fire-related it is an important consideration]. Low intensity underburning results in very little actual soil exposure - depending on cover, aspect, time of year when burned.

Forest Stand:

Unmanaged fire: Trees remain standing as live, dying or dead providing a source of shade and possibly a source of viable seed. (May also be harvested in salvage sales, however). Pre-burn fuel loadings often very high and include all sizes of fuels.

Managed fire: In underburns, boles and crowns undamaged or slightly scorched. In broadcast burns, small limbs and foliage removed. Large size material and stumps remain, though well-charred, depending on intensity of burn.

Forest Regeneration:

Unmanaged fire: Planting may be required. Natural process with seral brush or herbaceous species preceeding conifers by many years. (Adapted planting stock not always available). Plant succession usually regressed.

Managed fire: Planting stock availability is usually programmed in advance. The natural process of plant succession is usually not dramatically regressed.

B. Effects on Soil - Generalized

Research literature, reports, and observations relative to wildland fire effects are often confusing or seemingly contradictive largely due to a lack of complete data or defined terms and conditions. Frequently the data presented is "single function" oriented and/or reflects extreme fire situations. It is unusual to find a report that speaks to the range of fire intensities; the subtle changes (positive or negative), as well as the spectacular changes in natural processes on one study area. However, accumulating all of the available data provides the basis for some generalized statements: Fire, when prescribed or designed, can produce these direct and indirect beneficial soil effects:

1. Reduction of plant competition or undesirable species.

2. Enhancement of the plant community stability.

3. Exposure of mineral soil for natural seeding processes, i.e., site preparation.

4. Increased availability of nutrients.

5. Reduction of fuel loadings and wildfire potential.

6. Reduction of certain undesirable microorganisms.

Fire, when uncontrolled, has the potential to affect the following natural processes and usually represent "impacts":

1. Erosion - (accelerated)

2. Nutrient cycling - site productivity

3. Plant succession - vegetative recovery rate

The impacts or changes in these natural processes are inter-related. As erosion increases, site productivity and vegetative recovery rates decrease. As vegetative recovery rates decrease, erosion increases and site productivity decreases. The degree of impact is a function of the burn intensity, duration and inherent site conditions.

C. Effects on Soil - Summary of Research Literature

In an attempt to address the changes in the erosion, site productivity and vegetation recovery processes mentioned previously, it is frequently found in reviewing the literature that conclusions can be developed by inference. For example, there are numerous excellent research papers reporting on water repellency. This information is valuable since water repellency reduces infiltration. Repellency therefore, increases the transporting power of run-off waters and increases the potential for surface erosion. It also decreases the water available to plants thereby reducing vegetative recovery rate and ultimately site productivity.

There are a series of publications devoted to the effects of fire on soil, water, flora, fauna, air and fuels (see additional references) that provide a summary of research data nationally. General Technical Report WO-7 "Effects of Fire on Soil" (Wells et al. 1978) and others noted, provide some generalities and inferences that can be made which will provide the basis for conclusions to be made later.

Soil Temperature - Post-burn: The temperature differential between burned and un-burned sites is about 10°C (50°F) and hotter at 5 cm. (2") depth, decreasing rapidly with depth, shading and vegetative recovery rates. Surface soil temperatures on blackened soils at the surface have been recorded as high as 25°C (43°F) over natural conditions (Shearer 1974, Wells et al. 1978). This characteristic is important in the assessment of the vegetative recovery rate since it affects evaporation rates, frost heaving and root mortality.

Plant Roots: Shallow rooted species such as spruces and most true firs are damaged by ground fire, particularly when duff is consumed such as in wildfire. Most root mortality was restricted to upper 1.27 cm. (.6") of soils in a wildfire situation (Woodard 1977). However, it may include roots to 2.5 cm. (1") depth as reported on ponderosa pine stand by Milne and Grier (1979).

Rangeland Plant Species

Since rangeland species are of particular importance to our rangelands and forest-rangelands, the recovery rate of certain species are important for forage production as well as vegetation cover for retarding erosion. From Britton (1979) an overview of common species has been developed:

Big sagebrush (Artemisia tridentata) - easily killed by fire, does not resprout. Recovery or re-invasion depends on subspecies.

Mountain big sagebrush (A. tridentata subspecies vaseyana) - may re-occupy an area faster because it is found on more mesic sites.

Basin big sagebrush (A. tridentata subspecies tridentata) - slow to reoccupy area due to drier site preference.

Wyoming big sagebrush (A. tridentata subspecies Wyomingensis) - slow to re-occupy area due to drier site preference.

Three-tip sagebrush (A. tripartita) - can resprout.

Silver sagebrush (A. cana) - vigorous resprouter.

Rabbitbrush (Chrysothammus species) - various species can resprout vigorously.

Horsebrush (Tetradymin canescans) - vigorous resprouter.

Antelope Bitterbrush (Purshia tridentata) - weak to strong resprouter. Will vigorously resprout following fire on moist soils.

Desert bitterbrush (Purshia glandulosa) - vigorous resprouter. Fall prescribed burns result in higher mortality then cold spring burns for bitterbrush.

Bluegrass (Poa species) - slightly damaged by burning.

Cheatgrass (Bromus tectorum) - not appreciably effected, may increase in production.

Idaho fescue (Festuca idahoensis) - severely damaged in wildfires.

Junegrass (Koeleria crestata) - fire resistant.

Needlegrass (Stipa species) - severely damaged especially the first year.

Squirreltail (Sitanian hystrix) - fire resistant.

Wheatgrasses (Agropyron species) - fire resistant but recovery varies by species.

Note: See Martin and Dell (1978) for common tree species.

Soil Microorganisms: Heat from fire has a temporary sterilizing effect that may improve plant growth through the elimination of undesirable microorganisms. Positive and negative responses have been noted. Fungi are more susceptible than bacteria. Nitrifying bacteria are killed at low temperatures (Wells et al. 1978). Damping-off of seedlings has been observed on severe burns (Tarrant 1956). These factors can have a bearing on the selection of innoculated planting stock or nitrogen fixing species.

Organic Matter:

a. At temperatures of 100°C-200°C (212°F-392°F) non-destructive distillation of volatile organic compounds occurs.

b. At temperatures of 200°C-300°C (392°F-572°F) destructive distillation of up to 85% of organic substances occurs.

c. At temperatures over 300°C (572°F) the ignition point of carbonaceous materials is reached.

d. In intense burns of temps over 650°C (1202°F) destruction of all of the organic matter at the soil surface occurs.

e. Intense burns provide temps at 2.5 cm. depth great enough to distill much of the organic matter.

f. Moderate burns (approx. 432°C (810°F) at surface) are able to destroy most of the litter and duff.

g. Low intensity burns (approx. 250°C (482°F) or less) remove about 85% of the litter on the soil surface but only humic acids are altered at 2.5 cm depth. (DeBano, Dunn and Conrad 1977).

Chemical properties: Soil pH, phosphorous and exchangeable potassium, calcium and magnesium increase immediately after burning. Nitrogen can be lost by volatilization with losses of 10 to 20% of system total in chaparral and ponderosa pine types, (Wells et al. 1978). Ammonium nitrogen increases directly by fire intensity. Nitrate nitrogen is not changed during the fire but increases substantially during subsequent mineralization (Dunn and DeBano 1977). Nitrogen fixation (symbiotic and non-symbiotic) is more active following fires and may recover in some ecosystems. Some studies show no net change in total nitrogen after 10 to 20 years of periodic burning (Wells et al. 1978) Phosphorous losses begin with ignition stage (Woodard 1977). Sulfur losses have been detected indirectly and may be the most critical element of concern, due to the importance of sulfur in the formation of decomposition of soil organic matter, which in turn, is a major source of nitrogen (Grier and Klock 1979 and Klock 1979).

The following sketches from Klock (1979), provide an overview of the major differences between Westside and Eastside conditions in Oregon and Washington. The amount of total nitrogen contained in the forest floor represents significant management implication. The Eastside forest is represented with a total of 2668 kg/ha (2380 lb/ac) while the Westside condition is given as 36,282 kg/ha (32,363 lb/ac). It can also be noted that the opportunity for removal of total nitrogen from the system is greater on the eastside. It is possible to reduce that potential loss by protecting the forest floor layer. In essence, we must exercise greater control of the loss of the forest floor on those sites where the majority of the non-soil nitrogen is located in the duff and litter if we are to maintain the natural level of productivity.

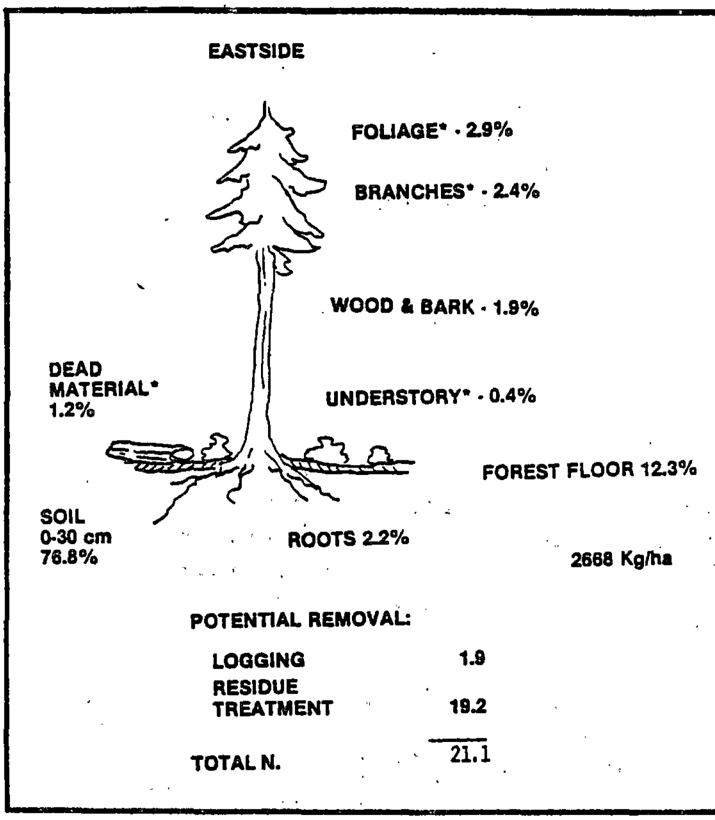

Figure 3 - Total Nitrogen Distribution

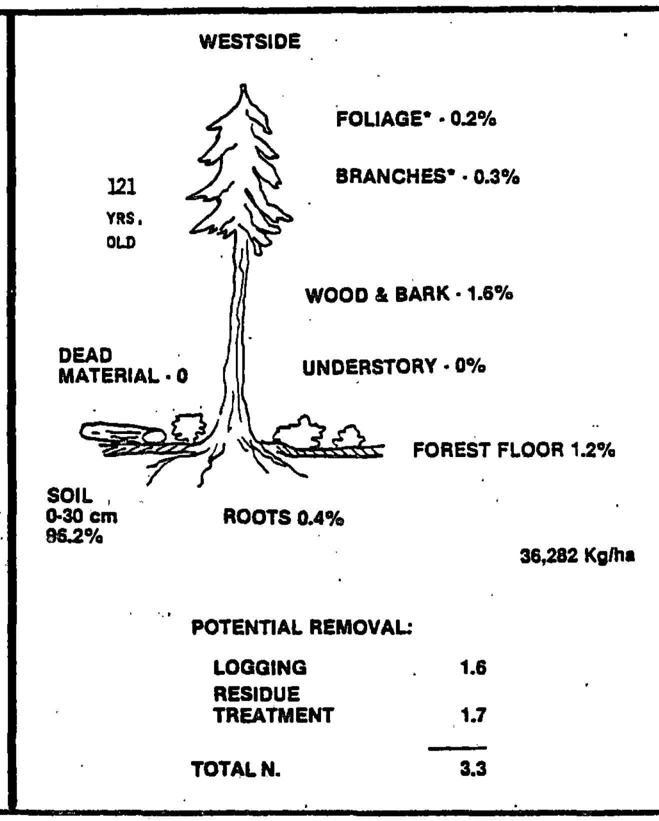

Figure 4 - Total Nitrogen Distribution

The following table (Table 5) serves as an example of the chemical changes that can take place on Westside conditions following a severe burn. There has been a significant loss in organic matter and a change in pH that tends to favor antagonistic microorganisms.

Table 5. Comparison of Nutrient Levels

SOIL 41, ALSEA R. D., SIUSLAW N. F.
70% WEST-FACING SLOPE - 6 MONTHS AFTER BURN

	0 - 1"	1 - 2"	2 - 3"	3 - 4"
	A - B	A - B	A - B	A - B
PH	5.4 - 6.3	5.3 - 5.8	5.8 - 5.8	6.0 - 5.9
P 1/	30 - 14	21 - 6	10 - 5	11 - 6
K 1/	449 - 429	371 - 413	257 - 347	234 - 347
CA 2/	14.3 - 7.0	6.9 - 6.1	6.0 - 4.9	4.8 - 4.7
MG 2/	4.4 - 2.2	2.3 - 2.9	2.0 - 2.6	1.6 - 2.6
TN 3/	.46 - .14	.29 - .13	.33 - .12	.16 - .11
O.M 3/	28.9 - 3.5	15.9 - 5.6	8.0 - 5.1	6.9 - 4.1

A = UNBURNED
B = BURNED
1/ = PPM
2/ = MEQ/100 GRMS
3/ = %
SAMPLED BY DIANE DRLICA 1/17/80
N = 15 SUBSAMPLES

Physical Properties: On exposed mineral soils, aggregates can be dispersed by rainfall impact. Pores become clogged and macro-pore space, infiltration and aeration are decreased, (Wells et al. 1978). Alteration of clay can also occur under severe conditions, (Ralston and Hatchell 1971). The inference can be made that the erosion potential is increased.

Water Repellency: This phenomena may occasionally occur in the litter layer, and frequently occurs in the ash dust layer, top of mineral soil layer or within a layer at a lower depth. The thickness of the water repellent layer depends on the intensity of the fire, the soil water content and the physical properties of the soil. It can occur as deep as 20 cm. (8") (Wells et al. 1978), but is typically found at shallower depths. Water repellency can be present without fire and often results from microorganism populations, particularly fungal mycelia. The action of heat on microbial decomposition products and undecomposed plant parts can intensify any water repellency present (Dyrness 1976). It has also been observed in sagebrush litter (Britton 1979).

In the sketch (Figure 5) provided by Agee (1979) it can be noted that a degree of natural water repellency can exist in several locations. Under low intensity fires it may increase in the upper portion of the forest floor but will not penetrate in depth to the mineral soil. However, high intensity fires may cause the water repellency to leave the upper portion of the forest floor and penetrate into the mineral soil.

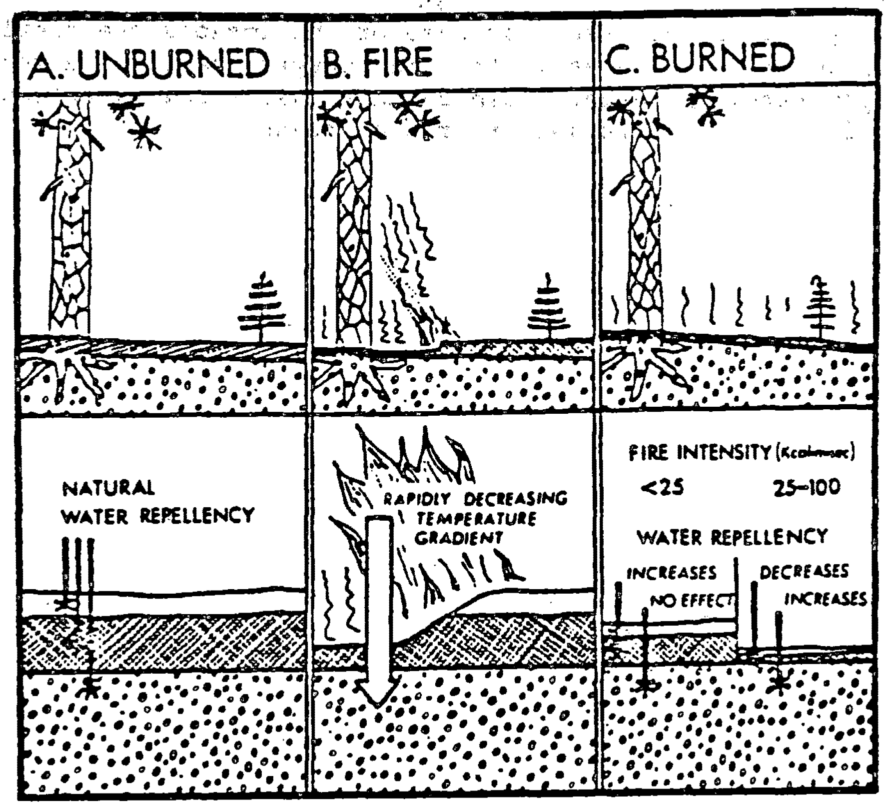

Figure 5 - Water Repellency Process (Agee 1979)

Persistence has been reported to last for 1 year in Montana, (DeByle 1973), up to 5 years in the Oregon Cascades, (Dyrness 1976), and up to 15 years under burned slash piles (Vogl and Ryder 1969), depending on the soil characteristics, fire intensity and duration and the plant litter type. DeBano (1968), suggests the following guidelines when using the water drop test: over 5 seconds represents non-wettable and under 5 seconds wettable, however he cautions that the water drop test while not always accurate it does appear to provide some immediate indications of the presence or absence of water repellency.

Surface Erosion: Susceptibility to wind, sheet, rill and dry ravel erosion can be increased due to the lack of protective vegetative cover. In Oklahoma, Ewell (Wells et al. 1978), reported that over a 9 year period, soil loss was 31 times as great on burned as on unburned woodlots. In the pine region of the Sierras, erosion was 2 to 239 times as great on burned areas (Wells et al. 1978). This data supports the concept that sediment production can be significantly increased and site productivity levels can be decreased. (This topic is thoroughly covered by Tiedeman et al. 1979).

Mass Wasting: This process has been reported in Wells et al. (1978) as insignificantly altered by fire, however, debris avalanching following the Eastern Washington fires of the early '70's was observed by this author. Mersereau and Dyrness (1972) also reported significant increases in mass movement in the Cascade Range forests following wildfire.

In summary, it can be seen that some of the impacts are single problems but most of those listed are integral parts of a more complex set of problems. Inferences can be made that possibly extend one set of data into one or more larger problem areas.

SECTION IV.

PROCESSES AFFECTED BY FIRE

IV. PROCESSES AFFECTED BY FIRE

Surface erosion, vegetative recovery rates and potential productivity are the major natural processes that can be altered by fire activities.

A. Surface erosion. As defined, is the detachment of soil or rock material and the transportation and/or deposition of this material from one place to another. The major factors involved are: soil conditions, topography, climate and plant cover.

1) Soil conditions include: a) the resistance of soil to detachment by rainfall impact, b) the infiltration rate, or how easily water enters the soil, c) the depth at which the first change and degree of change in permeability is encountered and d) the surface gravel content and size.

2) Topography influences the velocity of water movement and encompasses: a) slope length, b) slope roughness, c) slope configuration and d) position within the landscape. (These factors contribute to the areal extent of the surface erosion process).

3) Climate, particularily precipitation, is the driving force that is often referred to as the major agent of erosion. The different forms of climatic environments are also to be included in evaluating the erosion process. Rain dominated and snow dominated areas produce different expressions of erosion. Rain-on-snow events are also an important consideration.

4) The ground cover, living as well as dead material, modifies the effects of the erosion agents, i.e., wind and water. Research has shown that it requires 4480 to 6720 kg/ha. (4000 to 6000 pounds per acre) of ground cover to give nearly complete protection from rainfall impact and surface water flow. The forest floor or duff layer is the major erosion modifier.

For a frame of reference it has been reported (McConnell et al. 1971 and Williams et al. 1967) that 2.5 cm.-10 cm. (1-4") of Ponderosa pine litter is equivalent to 23.5 metric tons/ha. (10.5 tons/ac.). Fir and hemlock litter 1 cm.-16 cm. (.5-5.1") is equivalent to 18 to 170 metric tons/ha. (8-76 tons/acre).

5) Some other contributing influences that can affect the "normal process" is: changes in slope hydrology as the result of road and landing construction or induced water repellency. In some locations it is also suspected that, due to the blackened surface of post fire conditions, micro and macro climatic events are altered unfavorably and have an effect on a site.

Of all the factors which affect the erosion process as the result of fire activities, the loss of protective vegetative cover, (particularly the duff) and induced water repellency are the two most critical.

B. Vegetative Recovery rates are basically a function of soil conditions, climate and the plant community itself.

1) Soil conditions include the moisture and nutrient regimes. The moisture regime is controlled by the physical and biological properties of the soil. The duff and soil mantle thickness, particle size, organic matter content, aggregate size (soil structure), thermal properties as well as changes in hydraulic conductivity within the soil are some of the factors that cause a soil to have a favorable or unfavorable soil moisture regime. In addition, these same factors along with parent material, mineralogy and past use dictate the nutrient regime. In combination, they are basic to the plant community dynamics. The loss of the duff layer or any mineral soil layers has a dramatic effect on the types of pioneering species that occupy burned sites.

2) Climate is undoubtedly the prime controlling factor since it includes the moisture, light and temperature necessary to support plant life. The timing, amount and form of moisture within the growing season are the critical elements. Extreme air and soil temperatures, resulting from a reduction in shade or loss of insulating properties of the duff and litter following a fire, have an adverse effect on species composition occupying a site.

3) The plant community is an expression of a dynamic process that is constantly undergoing change. This is best described by Vogl, (1970) and paraphrased here: Plant succession can be dynamic with or without any appreciable change in species composition or without direction. It is a cyclic phenomenon and not a straight line replacement series. Within one climatic cycle there may be many erosion cycles each with its vegetative cycle. There are wet and dry cycles within any climatic cycle and when these are accompanied by lightning, fires result which produce fire caused vegetative cycles. Some vegetative types have situations where one wildfire breeds another, that is, the fuel-producing growth stimulated by one burn often builds and accumulates to where another fire is inevitable. "The rapid fuel accumulation, chemical nature of the fuels and slow decomposition rates not only invariably lead to fire but appear to be necessary to the sustained productivity of some communities..." "In many cases, reproduction requirements, growth rates, life spans, anatomical, morphological, physiological and chemical properties are adjusted to and play essential roles in these fire-induced vegetative cycles."

4) Fire can accelerate plant succession, cause retrogression or act as the renewal agent necessary to perpetuate vegetative cycles. Plant succession is basically dependent upon the effect of fire on the soil condition, and the condition of the residual vegetation and/or the seed source.

Martin et al. (1974) provides a sketch that depicts the complexity of plant succession patterns as a function of fire intensity. Under severe disturbance conditions, plant succession can retrogress to the seral or pioneer stage while under moderate disturbance it can progress as well as retrogress or remain in the present stage (see Figure 6).

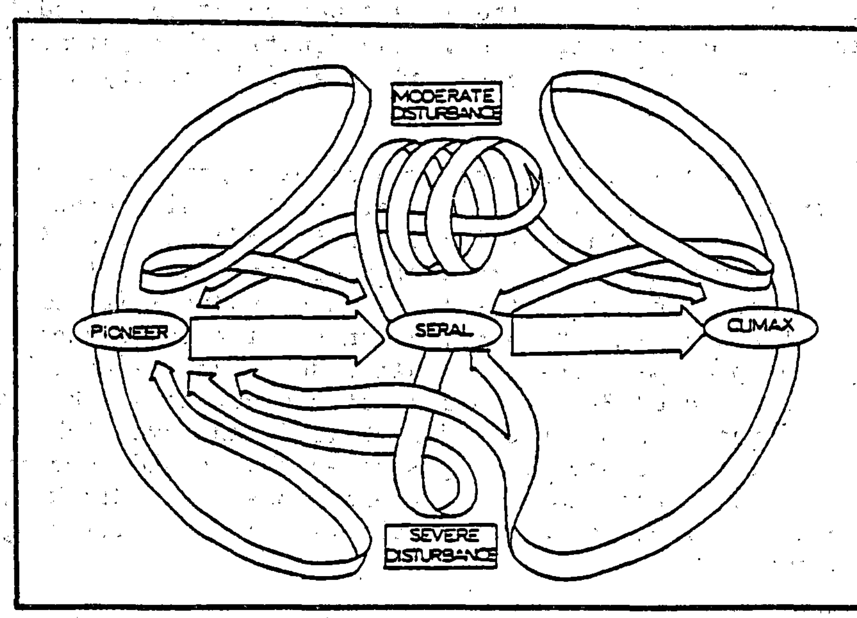

Figure 6 - Ecological Succession and Retrogression

"Severity of disturbances or perturbations as well as the susceptibility of the vegetation will influence the direction and degree to which succession is modified. Moderate disturbances may occur many times without moving the system forward or backward in succession, whereas severe disturbances will move the system toward earlier successional stages." (Martin et al. 1974).

5) Some of the contributing influences that affect the "normal" process of vegetative recovery include the presence or absence of big game, cattle or other herbivores and their effect on post-fire vegetation.

"Fire intensities also create differences, particularly when fuels have been reduced or concentrated by logging; when fires have been suppressed beyond their usual sequences permitting abnormal fuel build-up and vegetational decadence, or when controlled burns have been conducted under very poor burning conditions. Post-fire conditions necessary for plant establishment or re-establishment such as seed sources, seed production, seed dispersal, ash-bed effects, post-fire climate, including rainfall and erosion are perhaps more critical than fire intensities." (Vogl 1970).

C. Potential Productivity of a site is a function of soil conditions, climate and healthy adapted growing stock. Any functional impairment of the soil and water regimes affects a site and potential ability to support plant growth.

Productivity has been defined as the total amount of organic matter annually produced by an ecosystem. Fire may affect the maintenance of site productivity but the magnitude of its potential effect significantly depends upon the 1) ecosystem, 2) the intensity of fire and 3) the frequency of fire. Of major concern in the long-range productivity projection is the status of soil sulfur and the suppression of nitrogen-fixing species in the early stages of plant succession. Sulfur deficiencies have been noted in some fire perpetuated Pacific Northwest ecosystems which affect organic matter production. In addition, forest land management objectives often discriminate against nitrogen-fixing species that could re-supply the nitrogen status if given enough time, (Grier and Klock 1980, Klock and Grier 1980). An example might be the silvicultural discrimination against red alder or ceanothus.

Availability of many of the plant nutrients are dependent upon the decomposition of organic matter. The degree and rate of decomposition is a function of the microorganisms present, their food supply and soil environment (moisture and temperature). Of the many types of microorganisms necessary for this process, four groups are of particular importance: bacteria, actinomycetes, fungi and algae. These groups and their functions are briefly described in Table 6 from Pritchett (1979).

Table 6. Major Soil Microorganisms and Their Functions

Groups [1/]	Function
1. Autotrophic bacteria - Nitrosomonas	Oxidize ammonium nitrogen to nitrite nitrogen.
Autotrophic bacteria - Nitrobacter	Oxidize nitrite nitrogen to nitrate nitrogen which becomes available for plant intake.
2. Heterotrophic bacteria	Biologic nitrogen (N_2) fixation. Including atmospheric nitrogen fixation as well as fixation through free-living and symbiotic-relationship with higher plants.
3. Actinomycetes	Decompose cellulose and a wide range of organic materials. Produce complex molecules important to humus fraction of soils. Important in nodulation of Alnus and ceanothus species. Some are capable of synthesizing antibiotics lethal to antagonistic organisms.
4. Fungi	Major agents in decay of forest floor litter and duff including the cellulose and related compounds. Aid in nutrient cycling and soil aggregate stabilization. Sources of ammonium and simple nitrogen compounds. Serve as predators and contribute to microbiological balance. Form symbiotic associations called mycorrhizae with roots of higher plants.
5. Algae	Hasten the process of weathering. Generate organic matter from inorganic substances. Some strains assimilate atmospheric nitrogen - add to nitrogen supply.

1/ Heterotrophic forms require preformed organic nutrients to serve as sources of energy and carbon, while autotrophic forms obtain their energy from sunlight or by oxidation of inorganic compounds and their carbon by the assimilation of CO_2. (Alexander 1977).

SECTION V.

STANDARDS - HOW MUCH CHANGE IN THE NATURAL PROCESS CAN WE ACCEPT?

V. STANDARDS - HOW MUCH CHANGE IN THE NATURAL PROCESS CAN WE ACCEPT?

Developing a set of standards is necessary to predict whether a given activity will meet the desired end-results. One approach to this task is to search the literature for the "threshold values" of the various factors that make up the ingredients of a process. The following data aids in identifying and developing the standards for changes in soil site characteristics that affect one or all of the natural processes mentioned earlier.

Clay alteration: Temperatures between 100°C-200°C (212°F-392°F) drive off water held between adjacent miceles of montmorillonite and illite clays. At 550°C (1022°F) all forms of clay lose water derived from hydroxyl ions. At 980°C (1796°F) irreversible changes take place (Ralston and Hatchell 1971). This is particularly important to the changes in cation exchange capacities, and subsequently productivity, that can take place. In addition, loss of structual water permanently alters the shrinking and swelling properties of montmorillonite clays to the extent that heat-treated clay aggregates have soil moisture properties similar to sand or gravel which means they are subject to surface erosion.

pH: Heating soils at 315°C (600°F) increases pH as length of exposure is increased. A plateau of pH change is apparently reached at temperature of 482°C (900°F) regardless of duration. Changes in pH persist as a function of fire intensity and may last for several years (Tarrant 1953, 1954). The change in pH is important in the availability of nutrients to the plant as well as the requirements of desirable microorganisms.

Sulfur: Although little work has been done on this subject one report indicates that at temperatures of 800°C (1472°F), 50-56% of the total sulfur is oxidized (Woodard 1977).

Organic Matter and Total Nitrogen Losses:

a. At temperatures of about 650°C (1202°F), all organic matter at the surface is destroyed. Subsequent temperatures at 2.5 cm. (1") reaches 200-300°C (392°F-572°F) which will result in distillation. (DeBano et al. 1977).

b. At about 432°C (810°F) surface temperature (moderate burn), destruction of most of the litter layers take place.

c. Heating at 450°C (842°F) for 2 hours or 500°C (932°F) for 1/2 hr. was required to remove 99% of the organic matter in the soil materials tested (Ralston and Hatchell 1971).

d. Seventy percent loss of organic matter in the litter layer resulted in loss of about 44% of total nitrogen.

e. Twenty-five percent loss of organic matter in the litter resulted in small loss of total nitrogen (Dunn and DeBano 1977).

f. Over 500°C (932°F) surface temperatures produced 100% loss of total nitrogen in plant litter materials of pine.

g.

Destroying Temperatures	Percentage of Total Nitrogen
400-500°C (752°F-932°F)	75-100%
300-400°C (572°F-752°F)	50-75%
200-300°C (392°F-572°F)	50%
Below 200°C (392°F)	insignificant (Dunn and DeBano 1977)

Nitrate and Ammonia Nitrogen:

a. First signs of thermal decomposition of nitrogen compounds begins at 100°C (212°F).

b. Above 200°C (392°F) and up to 300°C (572°F), dramatic increases in nitrate nitrogen occur then decrease.

c. Nitrate nitrogen is completely destroyed at 500°C (932°F).

d. All amino acids are lost at 350°C (662°F), (Dunn and Debano 1977).

Ammonia nitrogen is increased directly by fire but nitrate nitrogen is not changed during the fire but increases substantially during subsequent mineralization.

Plant Tissues:

Lethal temperatures for protoplasm are about 50-60°C (122°F-140°F) for plant tissue. A fire of moderate intensity can kill thin-barked species; i.e., spruce, true firs, and lodgepole pine (Fowler and Helvey, 1978).

Grass Seeds:

Dry grass seeds will be killed by 5 minute exposure to temperatures of 121°C to 149°C (250°F-300°F), (Bently and Fenner 1958).

Microorganisms:

a. Nitrosomonas and nitrobacter group bacteria are destroyed at:

100°C (212°F) @ 2.5% soil moisture

or 140°C (284°F) @ 14.5% soil moisture.

(these groups do not recover quickly after a fire)

b. Hetereotrophic Bacteria

At 150°C (302°F) most were killed, while under the following conditions, they were destroyed:

210°C (410°F) @ 2.5% soil moisture

110°C (230°F) @ 14.5% soil moisture.

c. Actinomycetes

At 125°C (257°F) @ 2.5% soil moisture - destroyed

or 100°C (212°F) @ 14.5% soil moisture - destroyed.

d. Fungi

At 155°C (311°F) @ 2.5% soil moisture - destroyed

or 105°C (221°F) @ 14.5% soil moisture - destroyed

at 50°C (122°F) @ 14.5% soil moisture - only "heat shock" fungi remain (Dunn and Debano 1977).

Water Repellency

Temperatures initiating water repellency appeared to be in excess of 250°C (482°F) for 10 minutes (DeBano et al. 1976).

a. Subjecting a slightly water-repellent soil to surface temps. of:

°C	°F	Duration, minutes	Results (DeBano and Krammes 1966)
150	302	5, 10, 15, & 20	No increase in repellency
200	392	5, 10	No increase
200		15, 20	Increased repellency
260	500	5	Increased repellency
260		10	Impenetrable
315	600	5	Extremely repellent
315+		5	Impenetrable

b. In a normally wettable soil, peak water repellency was reached at:

°C	°F	Duration, minutes	Results (DeByle 1973)
150	302	20 to 90	No change
315	600	20 to 45	Induced repellency
315		20	On fungus containing litter-decrease

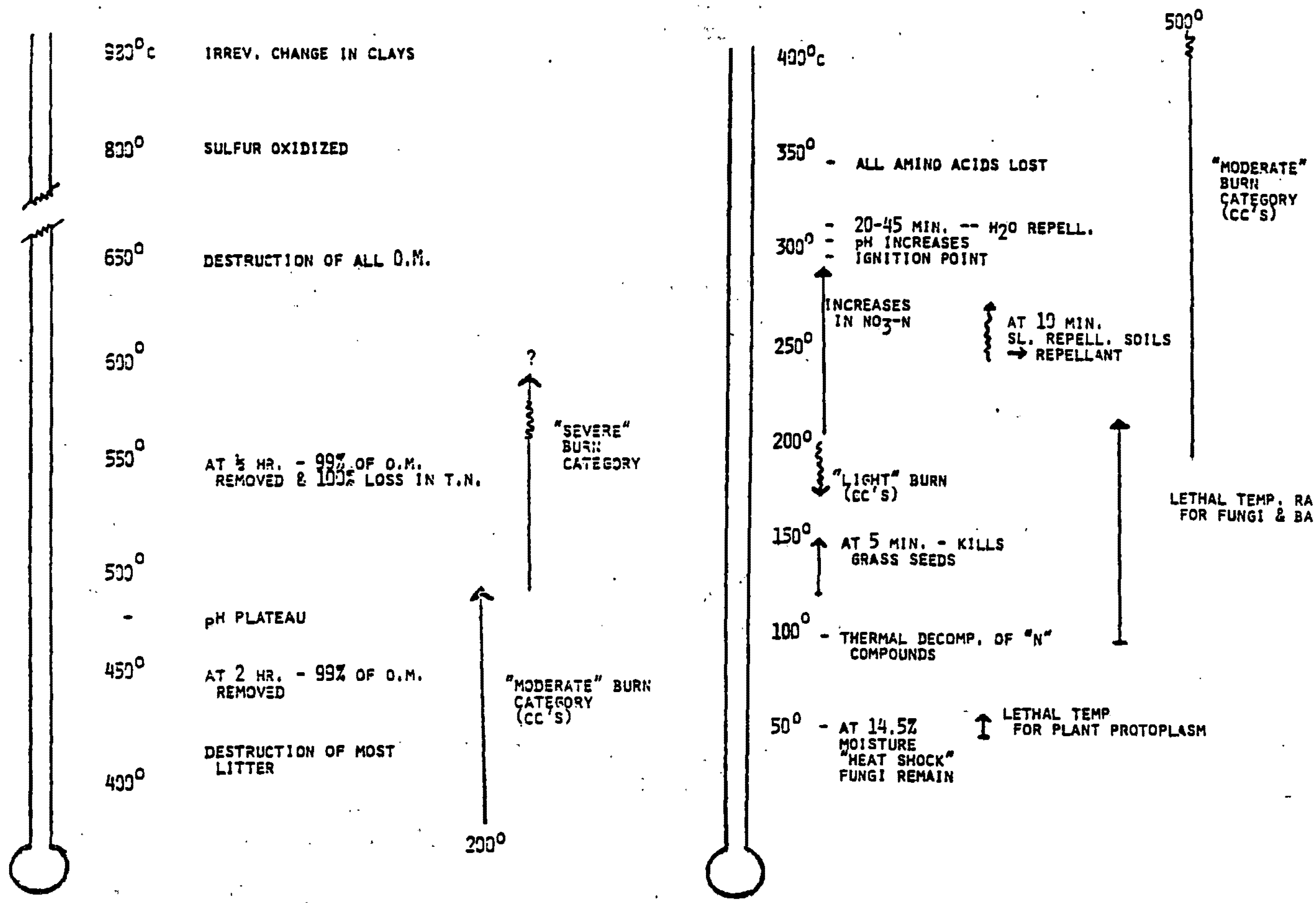

Figure 7 - Summary of "Threshold" Values

Vegetative Recovery:

Two plots examined by Steen (1965) in the Oregon Cascades over a 13 year period produced the following results:

Plot	2 yr.	4 yr.	13 yr.
A - 2% hard burn[1/]	10-15% cover	40-50% (some conifers)	100% stock, conifers
B - 23% hard burn	70% (groundsel)	85-95% (forbs & brush)	100% brush

1/ Hard burn was described as "organic material destroyed and some soil coloration."

Fireline Intensity

Using the classification presented in the "National Fire Danger Rating System" (Deeming et al. 1978) or Fire Management Analysis for Forest Planning (USFS-WO Draft 4 - January, 1980), it appears that at some point between fireline intensities of 100 and 500 Btu's/ft/sec. there should be a critical point relative to surface temperatures and residence burning time. However, it is impossible to make a correlation between these two factors. Therefore, an arbitrary value could be selected that best approximates the end-results required. Some fuel managers indicate that 100 Btu's/ft/s is a practical and achievable target value and this correlates with Hodgson's indication of "limit of good manual control" (Albini 1976).

Duff Reduction:

Below 30% moisture content, duff burns with no external heat source so that nearly all is consumed. Virtually no consumption of duff takes place at duff moisture levels above 120% (Sandberg 1980). See Figure 8.

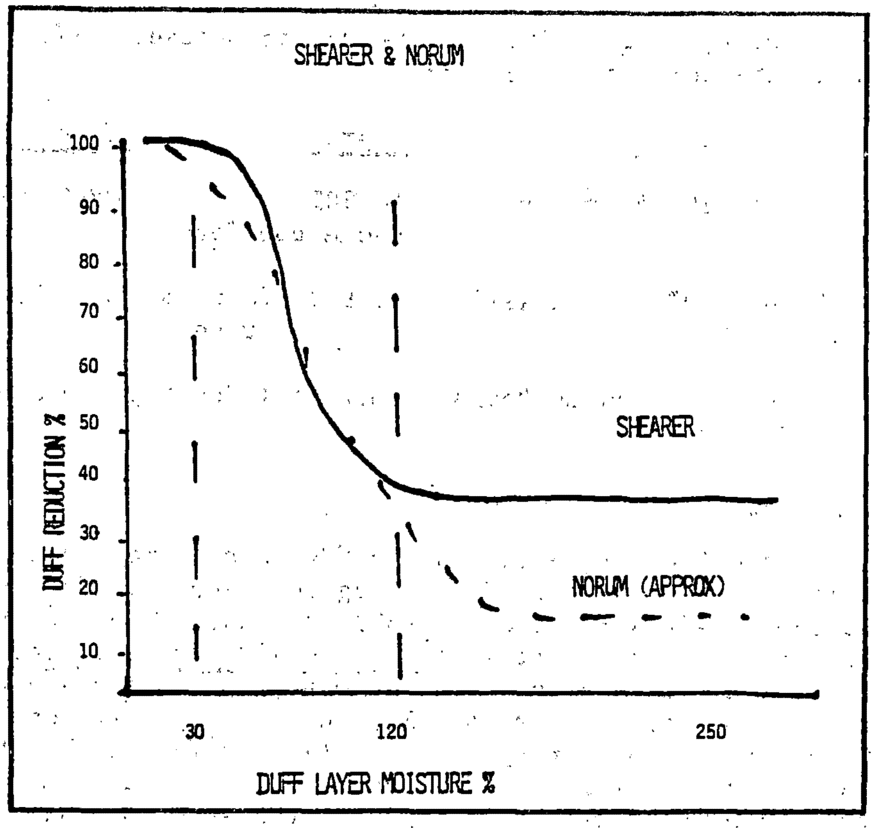

Figure 8 - Correlation between Duff Layer Moisture and Duff Reduction (Sandberg 1980)

Areal Extent:

As suggested in Wells et al. (1978) the areal extent of different proportions of burn intensities are as follows:

Area is severely burned when: more than 10% is severely burned,
more than 80% is moderately burned,
remainder is lightly burned.

Area is moderately burned when: less than 10% is severely burned,
over 15% is moderately burned,

Area is lightly burned when: less than 2% is severely burned,
less than 15% is moderately burned.

Standards:

Considering all of these threshold values, it appears that we can formulate some standards for most sites:

1. No significant change in protective capacity of the forest floor; (excluding silvicultural objectives!) i.e., discing for natural regeneration.

   a. No more than 40% bare ground exposed on soils of low to moderate erosion hazard rating.

   b. No more than 30% bare ground exposed on soils high erosion hazard rating.

   c. No more than 15% bare ground exposed on soils of very high erosion hazard rating.

It should be recognized that the existance of a soil with a high erosion hazard rating will be identified and will control the values given for the allowable losses. (A smaller acreage of an erodible soil in a sensitive position could create more total damage than a larger acreage of an erodible soil in an unsensitive position).

2. No significant loss in total nitrogen levels in the ecosystem. On westside forests, lower quantities of the total nitrogen are usually contained in the forest floor while on eastside forests the opposite usually occurs. A significant loss would be represented by a 50 percent reduction in total nitrogen in the top 5 cm. (2") of mineral soil.

3. No significant increase in water repellency. This requirement will have to be coordinated with items under 1 above since it has a direct effect on the erosion hazard potential. However, it can be assumed that a reduction in water infiltration in excess of 30% will have a substantial affect on plant available water and productivity.

4. Summary:

1. Significant change in protection capacity of the forest floor
   A. 40% bare ground exposed on soils of low to moderate erosion hazard
   B. 30% - high erosion hazard
   C. 15% - very high erosion hazard

2. Significant loss in total nitrogen levels
   50% reduction in top 2" of mineral soil

3. Significant increase in water repellency
   30% reduction in infiltration rates

		"Clearcut burns"	"Underburns"
4.	Surface temperatures	300°C (572°F)	200°C (392°F)
	Duration	10 minutes	10 minutes
	Soil temperatures @ 1"	175°C (347°F)	150°C (302°F)
	Fireline intensity	500 Btu's/ft/s	300 Btu's/ft/s

In developing a set of acceptable standards it is advisable to concentrate on some expression or change that is easy to visualize, measure and/or communicate to others. Of all the factors discussed, duff reduction and bare ground exposed appear to best fit these criteria. The amount of duff reduction is a factor common to the outcome of all three natural processes in question. Duff reduction can also be evaluated over the ranges of burn intensities and some inference regarding surface temperatures can be developed. At present, we do not have a direct correlation between burn intensity and soil temperature. However, an attempt has been made by Shearer (1974) to construct a theoretical duff reduction - soil temperature relationship (Figure 9). Even though this concept has not been field tested it does have application in that it provides some indication of the effects of duff reduction. In addition, the percentage of bare ground exposed is an indication of the amount of area subject to some form of erosion.

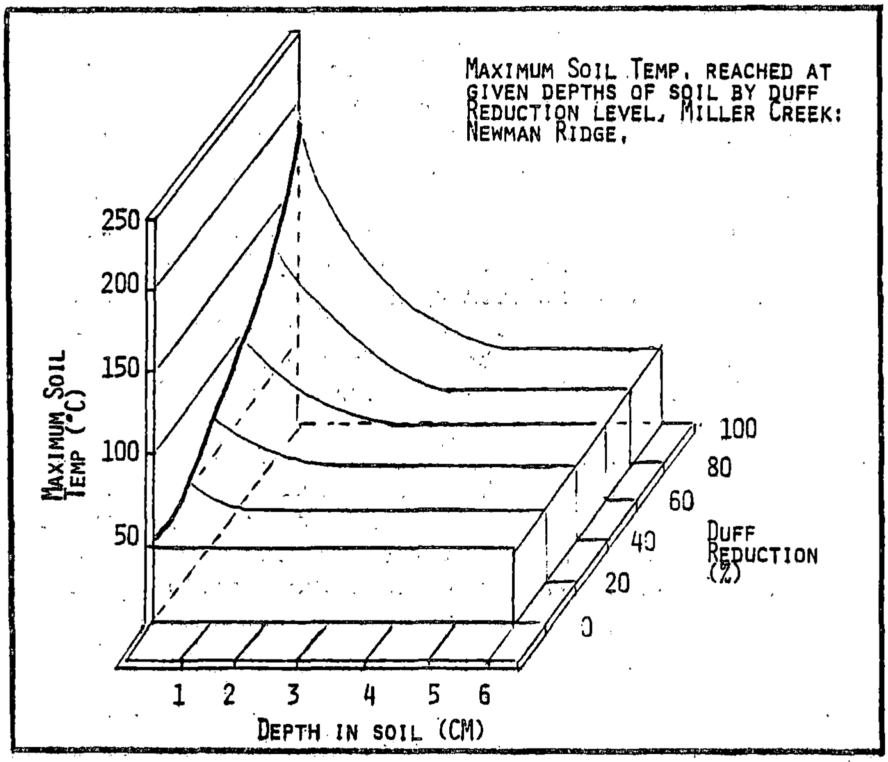

Figure 9 - Relationship of duff reduction, soil temperature and depth of soil. (R. C. Shearer 1974).

The erosion hazard and the nutrient cycling regimes should dictate the allowable loss of the duff layer. In some locations it has been suggested that 20% mineral soil exposure and 40% duff consumption are reasonable and practical acceptance levels. These values seem logical as long as the bare soil exposure is not concentrated in one location or does not occupy a highly sensitive site.

SECTION VI.

PREDICTION - HOW DO WE PREDICT WHAT WILL HAPPEN IN AREAS OF PLANNED OR UNPLANNED FIRE ACTIVITIES

VI. PREDICTION - HOW DO WE PREDICT WHAT WILL HAPPEN IN AREAS OF PLANNED OR UNPLANNED FIRE ACTIVITIES?

On any one fire, prescribed or wildfire, there is a continuum of behavior and effects. The task is to recognize the conditions of the treatment area in terms of its potential effects on all sites within the treated area.

The prediction process requires an interdisciplinary approach if the desired results are to be obtained. This concept applies to Fire Management's input to Land Management Planning as well as to planned prescribed burning. It takes more than one area of specialization to be able to identify the important parameters as well as a utilization of the predictive tools such as mathematical models. Basically, predictions are made by transferring the cause-effect relationships associated with known conditions into other areas of similar conditions. Some of this work has been done and is found in PNW-33 "Forest Residues Management Guidelines for the Pacific Northwest," Pierovich et al. (1975), and "Planning for Prescribed Burning in the Inland Northwest," PNW-76, Martin and Dell (1978). Both of these documents are an excellent source. PNW-33 is broad in scope but the same concepts that are mentioned apply to local conditions. Certain topographic, soil, vegetation and fuel loading conditions can be observed that provide indications necessary for predicting the effects of fire. Some of these conditions influence fire behavior while others pertain to the erosion process, vegetation recovery rate and/or productivity potential.

1) Topographic:

a) Slope configuration: V-shaped features, commonly found in drainage ways, have the potential to get considerably hotter than smooth slopes due to the trapping of hot air and the radiation of energy from one slope face to another. Concave slopes also have the potential to trap heat while convex slopes allow for its release but are usually representative of shallow soils and harsh sites with slow vegetative recovery rates.

b) Aspect: This feature relates to the vegetative recovery rate and fire behavior influences, that is, higher air temperatures, lower relative humidity and fuel moisture levels. Southerly facing slopes are slower to recover than northerly facing slopes even though the fuel loadings can be significantly less. Solar radiation and therefore, evaporation rates are also greater, resulting in fuel and duff moisture values which are invariably lower.

c) Slope gradient: Slopes in excess of 50 percent gradient respond to fire differently than do the gentler slope gradients. Duration of the fire front may be the same, but pre-heating capabilities usually occur on steep slopes and an increase in rate of spread can be expected. Again, these slope gradients generally indicate shallow soils with harsh sites and vegetative recovery rates are usually slower.

2) Soil Characteristics:

a) Duff thickness: Forest floor layers less than 2 cm. (1") in thickness lack the capacity to absorb the effects of fire. Those thicknesses in excess of 5 cm. (2") are better able to withstand fire, provide insulation to the mineral soil and protect the soil from erosion processes as long as the duff is not consumed.

Shallow thicknesses of duff have lower moisture holding capacities and therefore are easier to pre-heat and ignite than are thicker quantities. Duff thickness is also an indication of vegetative recovery rates. The shallower thicknesses indicate sites which are prone to be slower in recovery. Frequently the right conditions are provided for brush release.

b) Soil organic matter content: Mineral soil layers with less than 2% organic matter content usually represent harsh conditions for vigorous plant support. Those in excess of 4% are considered "fertile." In addition to providing increased resistance to erosion, this factor represents a key to potential productivity and vegetative recovery. Also, moisture holding capacities are proportionately greater with increasing organic matter content and therefore cooler for longer periods of the year.

On those lands that lack a forest floor layer of sufficient thickness, organic matter content would become a very important parameter in the prediction process.

c) Moisture-holding capacities: The amount of water held in the soil and made available for plant growth is the key to vegetative recovery rates and is basic to potential productivity. The capacity to accept and store given quantities of water is also essential to the soils resistance to surface erosion. Those soils with less than 3.8 cm. (1.5") of water storage per 30 cm. (12") of soil material are usually considered harsh and of low potential productivity. In contrast, those soils with water storage capacities greater than 6 cm./30 cm. (2.5" of a available water per foot of soil) of soil are much more resistant.

d) Soil Texture: This soil property relates to the erosion process, vegetation recovery rate, and productivity. Soils with high gravel or stone contents respond to fire much the same as the coarse textured soils. Medium textured soils, with their inherent water holding and plant available water quantities provide greater productivity potentials. Therefore, under favorable climatic conditions, these soils produce greater biomass that contribute to thick duff layers or higher organic matter contents.

Excluding coarse volcanic ash (pumice), coarse textured soils have high thermal diffusivities and thermal contact coefficients. Therefore, heat can be transmitted to greater depths in a shorter period of time. Because of their smaller air void sizes, fine textured soils transmit heat at a lower rate. Because of their lack of density, coarse ash soils are less responsive to heat transfer. The transfer of colloidal organic substances that produce water repellency is inherently greater in coarse textured soils, and less in medium or fine textures. However, under wildfire conditions and under lodgepole pine vegetation cover water repellency has been observed on "pumice" soils.

Table 7.

Some Generalizations by Soil

Textural Groupings1/

	Coarse	Medium	Fine	"Pumice"
Erosion Hazard2/	High	Low	Medium	Low
Productivity Potential3/	Low	High	Med-High	Low
Vegetative Recovery Rate3/	Slow	Rapid	Medium	Slow
Water Repellency Hazard3/	High	Medium	Low	Low

1/ = Textural groupings include:

coarse: sands, loamy sands, medium and coarse sandy loams.

medium: loams, silt loams, "light" clay loams, "ashy" silt loams, and fine and very fine sandy loams.

fine: clays, clay loams, silty clays, silty clay loams, sandy clays and sandy clay loams.

"pumice": volcanic ash > .05 mm.

2/ = Low erosion hazard refers to sheet erosion process and excludes concentrated waters.

3/ = These ratings are based on Douglas-fir (westside) and Douglas-fir/Ponderosa pine (eastside) timber type-climatic zones.

e. Erosion Hazard - This rating can be developed by using either one of two accepted methods:

1. Title 2500 - Watershed Management

   Region 5, Supplement No. 18

   Chapter 2550 - May 1976 (see Appendix)

2. USDA - Soil Conservation Service

   Technical Notes

   Woodland - No. 10, Sept. 1977

   "Estimating Sheet - Rill Erosion and

   Sediment Yield on Disturbed Western

   Forest and Woodlands"

3) Plant communities-litter types: Some plant communities are recognized as being particularly troublesome as far as water repellency is concerned. Some are naturally water repellent due to fungal mycelia levels while some repel water because of the organic compounds that are volatilized during high temperatures.

   The following is a partial listing of those plant communities which require cautious consideration (source: DeBano 1968, Dyrness 1976, DeByle 1973, Hall 1973):

   a) Severely water repellent.* Mtn. Mahogany, scrub oak, Deer brush, Sugar bush, Lodgepole/lupine, and Subalpine fir/grouse huckleberry.

   b) Moderate to severely water repellent: Lodgepole/big huckleberry, Lodgepole/grouse huckleberry, White fir/big huckleberry and grouse huckleberry, White fir/twin flower-forb, and subalpine/big huckleberry.

   c) Slight or temporary water repellency: Douglas-fir/western larch.

4) Fuel Loadings: Forest fuel loadings can be determined by procedures outlined in the "Users' Guide" (Snell et al. 1979). A very acceptable alternative, the Photo Series method of quantifying fuel loadings as explained by Maxwell and Ward (1976), (USDA Forest Service General Tech. Reports PNW-51 and 52) can be used.

   The next step in the consideration of fuels is to determine if desired fuel moisture levels can be achieved and at during which period of the year they are most likely to reach those levels. This step can be supported by the use of the Fort Collins Computer program "REGIM." or "BURP." (contact Watershed Systems Development Group, Ft. Collins). This is simply a bookkeeping system that accounts for moisture into a soil system and moisture out by evaporation and transpiration. It can provide some expected periods of moisture excesses that can be used as indicators to desired duff and fuel moisture contents.

Other fire behavior models that utilize various meteorological conditions could be incorporated, such as "PRESCRB" (Furman 1978).

The last step in the prediction process is to utilize prediction nomograms as presented in "Estimating Wildfire Behavior and Effects", Albini (1976) for the purpose of predicting the wildfire behavior characteristics.

In summary, this portion of the prediction process has been arranged so that a "checklist approach" can be made of the factors that might be considered in the development of the duff reduction and bare ground exposure criteria.

1) Topographic Features	Relative Hazard Rating
Slope Configuration	
Benches, valley fills, "flats"	Low
Concave and convex	Medium
V-shaped	High
Aspect	
North, northwest, northeast	Low
East, southeast	Medium
Southwest, south, west	High
Slope Gradient	
0-25%	Low
25-50%	Medium
50+%	High

2) Soil Characteristics

Duff Thickness

10 cm. + (4" +)	Low
5-10 cm. (2-4")	↓
< 5 cm. (< 2")	High

Soil Organic Matter

4% +	Low
2-4%	↓
< 2%	High

Water Holding Capacity

> 6 cm./30 cm. (> 2.5"/ft. of soil)	Low
3.8-6 cm./30 cm. (1.5-2.5"/ft. of soil)	↓
3.8 cm./30 cm. (< 1.5"/ft. of soil)	High

Soil Texture

Medium and ashy silt loams	Low
Fine and coarse ash (pumice)	↓
Coarse	High

Surface Erosion

Low	Low
Moderate	↓
High	High

3) Vegetation

Water Repellency

Douglas-fir types and Rangeland	Low
Upper elevation types and some lodgepole	↓
Shrub species and some lodgepole	High

4) Fuel Loadings

a. For clearcut-slash areas (all sizes)

0-45 tons/ha. (0-20 tons/ac.) evenly distributed	Low
45-134 tons/ha. (20-60 tons/ac.) evenly distributed	↓
134 + tons/ha. (60 + tons/ac.) evenly distributed	High

b. Partial cut slash areas (all sizes)

0-34 tons/ha. (0-15 tons/ac.) evenly distributed	Low
34-90 tons/ha. (15-40 tons/ac.) evenly distributed	↓
90 + tons/ha. (40 + tons/ac.) evenly distributed	High

c. Natural fuel areas (all sizes)

0-22 tons/ha. (0-10 tons/ac.) evenly distributed	Low
22-56 tons/ha. (10-25 tons/ac.) evenly distributed	↓
56 + tons/ha. (25 + tons/ac.) evenly distributed	High

Note: To aid in the visualization of natural or activity created fuel loadings, the reader is directed to the Pacific Northwest Forest and Range Experiment Stations' photo series by Maxwell and Ward (1976 and 1980).

SECTION VII.

PRESCRIPTION - HOW DO WE DESIGN OUR ACTIVITY TO MEET ACCEPTANCE LEVELS?

VII. PRESCRIPTION - HOW DO WE DESIGN OUR ACTIVITY TO MEET ACCEPTANCE LEVELS?

We must specify the fire characteristics that will produce the desired results, then either schedule for or otherwise create those characteristics. The fuels complex can be manipulated to remove coarse fuels before hand, or by lighting techniques that reduce coarse fuel involvement. Monitoring the moisture content in the heavy surface fuels and in the duff will also indicate the opportunities for burning (Sandberg 1980). Scheduling of the burning can be developed for a range of conditions under which desired effects can be produced which will provide latitude for ignition design and utilization of manpower.

There are several excellent sources of design criteria procedures. Each source deals with different plant communities and site conditions. Some of these are:

Martin and Dell, 1978 - Ponderosa pine and other inland plant communities

Fischer, 1978 - Ponderosa pine/Douglas-fir

Norum, 1977 - Larch/Douglas-fir

Beaufait et al. 1975 - Larch/Spruce/Douglas-fir

Sandberg, 1980 - Coastal Douglas-fir underburn

Duff Reduction Equations

In addition to these reports there are several sources of duff reduction prediction equations available for use and testing with some of our Region 6 timber types. These are described briefly as:

FROM SANDBERG, PNW 285 1980, "DOUGLAS-FIR DUFF REDUCTION"

DUFF REDUCTION EQUATION FOR COASTAL D.F. PRESCRIBED UNDERBURNS

AFTDUFF = - 6.76 + .99 BEFDUFF + .14 NFDR-Th

AFTDUFF = DUFF REMAINING - CENTIMETERS

BEFDUFF - PREBURN DUFF THICKNESS - CENTIMETERS

NFDR - Th = 1000 HOUR TIMELAG MOISTURE CONTENT

Figure 10 - "Douglas-fir Duff Reduction" - Sandberg

FROM SHEARER, 1975, "SEEDBED CHARACTERISTIC IN WESTERN LARCH FORESTS AFTER PRESCRIBED BURNING" U.S.D.A.-F.S. RESEARCH PAPER INT-167.

DUFF REDUCTION EQUATION - WESTERN LARCH - MONTANA

$$DR = 100 - 63.772\, e^{\left(\frac{\frac{MC}{220}-1}{0.7}\right)^{8}}$$

MC = DUFF MOISTURE CONTENT, $0 \leq MC \leq 220$

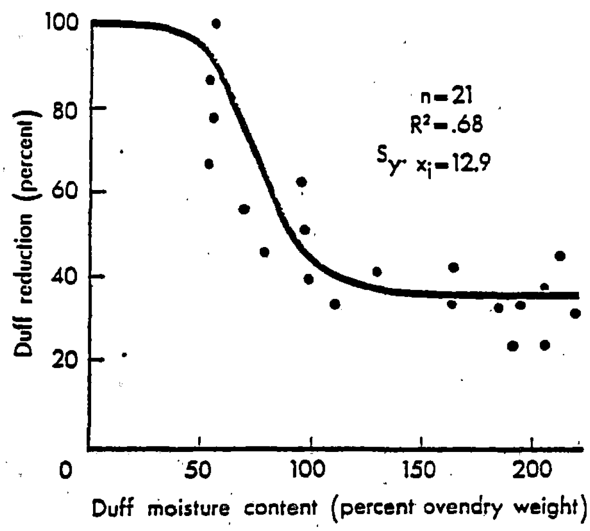

Figure 11 - Duff reduction equation - Shearer. Duff reduction related to water content of the lower half of the duff layer.

DUFF REDUCTION EQUATION FOR WESTERN LARCH - MONTANA

DUFF REDUCTION IN CM. = FUNCTION OF: UPPER DUFF MOISTURE CONTENT, BUILDUP INDEX, SQUARE ROOT OF BUILDUP INDEX

$$Y(2) = F(X(2), X(7), X(12))$$

$$Y(2) = -4.1528 - 0.00224X(2) - 0.05021X(7) + 1.3144X(12)$$

$$R^2 = 0.53$$

Y(2) = DUFF REDUCTION IN CM.

X(2) = UPPER DUFF MOISTURE CONTENT IN %

X(7) = BUILDUP INDEX

X(12) = $\sqrt{\text{BUILDUP INDEX}}$

FROM BEAUFAIT, HARDY & FISCHER, 1977, "BROADCAST BURNING IN LARCH-FIR CLEARCUTS" USDA-FS RESEARCH PAPER INT-175, REVISED.

Figure 12 - Duff Reduction Equation - Beaufait et al.

Due to the extreme variations in duff thickness, particularly in the various age classes of Ponderosa pine types, a duff reduction equation for use in Region 6 is not yet available.

The report by Sandberg (1980) is of particular interest since he provides several formulae for predicting duff reduction and thereby specifying design criteria. In his report he has made a correlation between the NFDR 1000 hour timelag fuel moisture levels and lower duff moisture values. (The 1000 hour timelag values relate to the roundwood diameter size of 7.6 cm.-20 cm. (3 to 8") category). See Table 7. For the purposes of design criteria he feels that moisture levels above 18% in the NFDR 1000 hour timelag fuels and 30% in the lower duff levels are acceptable moisture levels while those below this value would produce undesirable results in underburns in coastal Douglas-fir underburning. Utilizing this concept would eliminate the duff moisture determination in preference to the fuel moisture determination which could be done electronically and swiftly.

Table 8.

NFDRS DEAD FUEL CLASSES			
	FUEL		
TIMELAG CLASS	ROUNDWOOD (DIAMETER)		LITTER (DEPTH)
	- - - - - - - - INCHES - - - - - - - -		
1-HOUR (0-2 HOURS)	To ¼	(.6 CM.)	To ¼
10-HOUR (2-20 HOURS)	¼ TO 1	(.6-2.5 CM.)	¼ TO 1
100-HOUR (20-200 HOURS)	>1 TO 3	(2.5-7.6 CM.)	>1 TO 4
1,000-HOUR (200-2,000 HOURS)	>3 TO 8	(7.6-20 CM.)	>4 TO 12

In Sandberg's (1980) report he also compares percent duff reduction to mineral soil exposure. He provides the following graph and indicates: "The figure may best be used to determine which objective is the greater constraint on planning a prescribed fire. For example, mineral soil to be exposed is typically specified as less than 20 percent. An objective to reduce duff by 50 percent or more would be in conflict with that specification!"

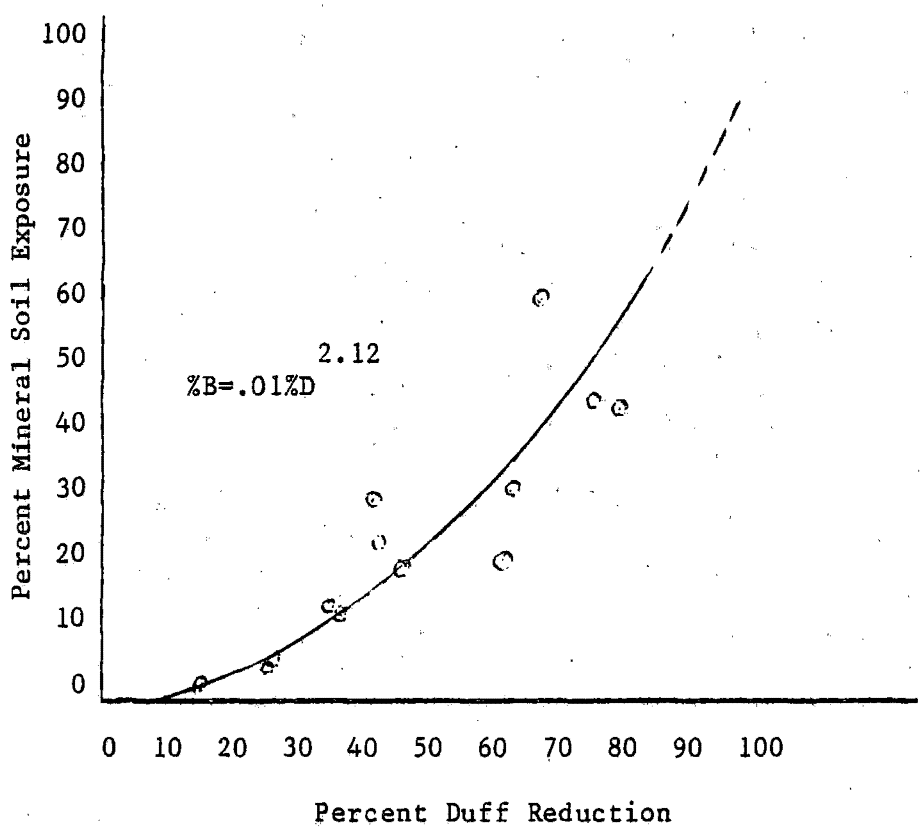

Figure 13 - Relationship of Duff Reduction and Mineral Soil Exposure (Sandberg 1980)

Norum (1979) has offered some "rule of thumb" values that relate to moisture content of small (<4" or 10 cm.) diameter fuels. He feels that moisture contents between 10 and 17 percent in the small diameter fuels is a safe and practical range. He further states that fuels burned in this range of moisture content will be approximately 78% consumed. He also has provided a table of predicted duff consumption for western larch/Douglas-fir fuel types: (See Table 9)

Table 9. Percentage of duff depth reduction predicted from duff water content and fuel consumption

Water content of lower half of duff layer	Tons per acre (t/ha) of small (<4 inch or <10 cm. diam.) fuels consumed			
	5(11)	10(22)	15(34)	20(45)
Percent	--- Percentage of duff depth reduction ---			
5	60	78	90	100
10	59	78	90	100
15	57	78	90	100
20	55	77	90	100
25	53	77	90	100
30	51	76	90	100
35	48	74	89	100
40	46	73	89	100
45	43	70	89	100
50	41	68	88	100
55	39	65	87	100
60	36	61	85	100
65	34	58	83	99
70	32	54	80	99
75	30	49	77	98
80	28	45	73	97
85	26	41	69	96
90	24	36	64	95
95	22	32	59	94
100	21	29	53	92
105	19	25	47	89
110	18	22	41	86
115	17	19	36	82
120	15	17	31	78
125	14	15	27	73
130	13	14	23	68
135	12	13	21	62
140	11	12	19	56
145	11	11	17	50
150	10	11	16	44
155	9	11	16	38
160	9	10	16	34
165	8	10	15	30
170	8	10	15	27
175	7	10	15	24
180	7	10	15	23
185	6	10	15	22
190	6	10	15	21
195	6	10	15	21
200	6	10	15	21
205	5	10	15	21
210	5	10	15	21
215	5	10	15	21
220	5	10	15	21

Alternatives

In addition to the design criteria it may be quite useful to explore some of the alternatives or modifications that we have available such as:

1. Yard unmerchantable material - "Y.U.M."
2. Winter burn
3. Brown and burn
4. "Jack-pot" burning
5. Lop and scatter
6. Mechanical treatment (may be last resort in many cases)
7. No burn, particularly on slopes with extreme regeneration problems.

SECTION VIII.

MONITORING - HOW DO WE CHECK TO SEE THAT OUR DESIGN WAS EXECUTED AS PRESCRIBED, IF THE DESIGN WAS ADEQUATE, AND/OR IF OUR PREDICTIONS WERE ACCURATE?

VIII. MONITORING - HOW DO WE CHECK TO SEE THAT OUR DESIGN WAS EXECUTED AS PRESCRIBED, IF THE DESIGN WAS ADEQUATE AND/OR IF OUR PREDICTIONS WERE ACCURATE?

This can be stated simply: Document, observe, measure, and document. It also helps immeasurably if all parties concerned in the prescription are actively involved in the operation.

Since we are dealing with a great variety of inherent variabilities we shouldn't anticipate perfection in the end results. We can, however, expect an acceptable job. Sudden unexpected changes in the desired climatic factors favorable to the prescribed burn and usually occurring while the burn is in progress are probably the most common cause of less-than-desired results. Variabilities in fuel loading, fuel moisture, and duff moisture levels are also sources of fall-down. In the "prediction" process these considerations should be included and design changes can be modified or accepted as is recognizing the risk involved.

Monitoring should be considered in two phases, short-term and long-term. There are some obvious effects of a burn that can be measured or observed immediately. Long-term effects require careful thought and considerable advance planning and data gathering. Some of the items to measure and/or observe include:

1) Fuel consumption - (usually short-term consideration)

   a. Amount of fuel reduced by size class

2) Fuel classification (short and long-term)

   a. Fuel hazard classification

      1) pre-burn

      2) post-burn

      3) future conditions

3) Duff reduction (short-term)

   a. Pre-burn thickness and character, i.e., water repellency and nature of decomposition

   b. Post-burn thickness and change in character

4) Soil Exposure (short and long-term)

   a. Pre-burn area, form of erosion and quantity of sediment

   b. Post-burn area, form and quantity of sediment

   c. Future - change in form and quantity of sediment

5. Vegetation (short and long-term)

   a. Pre-burn composition, quantity and quality

   b. Post-burn composition, quantity and quality

   c. Future vegetation recovery rates and stages

6. Productivity (short and long-term)

   a. Pre-burn pH, organic matter, and total nitrogen contents

   b. Post-burn pH, organic matter, and total nitrogen

   c. Future effect on stand development and vigor

Transect measurements utilizing large nails or spikes serve as a useful technique for duff reduction measurements. This process is discussed in "Broadcast Burning in Larch-fir clearcuts - The Miller Creek - Newman Ridge Study" USDA Forest Service Research Paper INT-175 revised (Beaufait, Hardy and Fischer 1977). In this study 20 cm. (8") long spikes were driven into the soil so that the head of the spike rested on the pre-burn duff level. Following the burn, the ashes were blown away from the spikes and the exposed spike length was recorded. The spikes were set in conjunction with the fuel inventory transects.

Another monitoring procedure consists of collecting soil samples on the pre-burn and post-burn conditions for nutrient status. Sample depths of 1 inch increments will be more useful than commonly sampled depths. A major difficulty with this process is the inherent variability encountered in soil sampling pits and the need for a great number of samples in order to meet statistical validity requirements. Nevertheless, it may be the only way to document changes in productivity potential.

Temperature sensitive compounds can be smeared or painted on smooth surfaces, such as glass, or asbestos placards and can also be installed at various soil depths to provide temperature data. These commercially available devices are relatively inexpensive and simple to use. They could be used in conjunction with the spikes if it was desired to develop some base line information.

Mitigation measures could also be designed into the prescription or monitoring phase. In areas where some water-repellency is developed, scarification by machinery, such as disc-harrows, could be employed. Erosion control seeding and fertilizing might also be programmed as part of the contingency plan.

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CONVERSION FACTORS

To Convert	*To*	*Multiply By*
Acres	Hectares	0.4047
Btu	Kilojoules	1.055
Calories	Joules	4.186
Calories	Kilojoules	0.004186
Centimeters	Inches	0.3937
Cubic feet	Cubic meters	0.02832
Cubic feet/acre	Cubic meters/hectare	0.06998
Cubic meters	Cubic feet	35.31
Cubic meters/hectare	Cubic feet/acre	14.29
Feet	Meters	0.3048
Grams/square centimeter	Kilograms/square meter	10.0
Grams/square meter	Kilograms/square meter	0.001
Hectares	Acres	2.471
Inches	Centimeters	2.540
Joules	Calories	0.2389
Kilograms	Pounds	2.205
Kilograms/square meter	Grams/square centimeter	0.1
Kilograms/square meter	Pounds/square foot	0.2048
Kilograms/square meter	Tonnes/hectare	10.0
Kilograms/square meter	Tons/acre	4.461
Kilojoules	Btu	0.9480
Kilojoules	Calories	238.9
Meters	Feet	3.281
Pounds	Kilograms	0.4535
Pounds/square foot	Kilograms/square meter	4.883
Pounds/square foot	Tons/acre	21.78
Tonnes	Tons	1.023
Tonnes/hectare	Kilograms/square meter	0.1
Tonnes/hectare	Pounds/square foot	0.02048
Tonnes/hectare	Tons/acre	0.4460
Tons	Tonnes	1.102
Tons/acre	Kilograms/square meter	0.2243
Tons/acre	Pounds/square foot	0.04591
Tons/acre	Tonnes/hectare	2.242

(Martin et al. 1979)